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TWR-60187

SPACE SHUTTLE

Solid Rocket Motors
Thiokol Corporation

Follow-on Cable Coupling Lightning Test Final Test Report

Volume III--Appendixes E and F

31 October 1990

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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Thiokol CORPORATION

SPACE OPERATIONS

P.O. Box 707, Brigham City, UT 84302-0707 (801) 863-3511

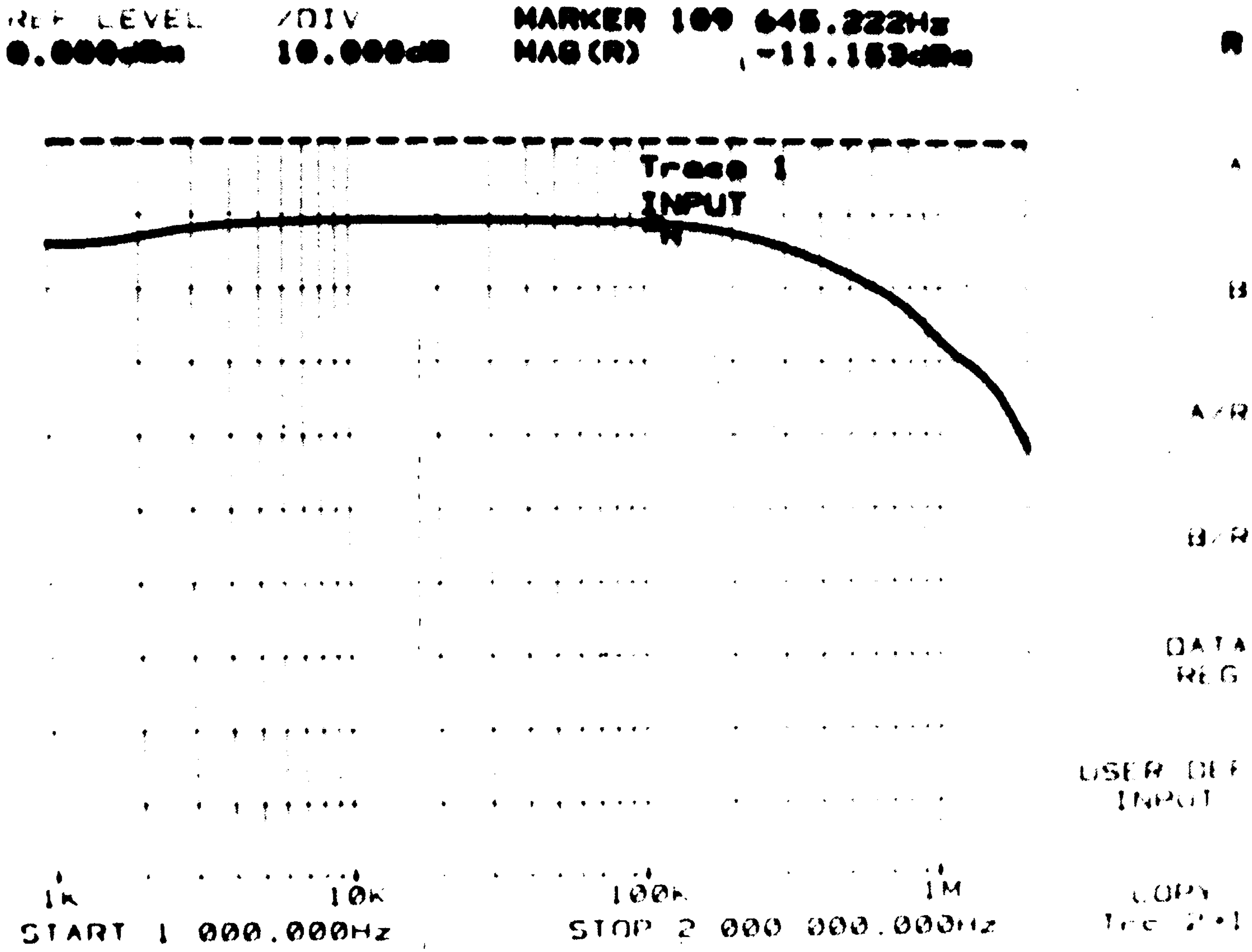
Publications No. 91230

CONTENTS

Volume III

Appendix E

Follow-on Cable Coupling Lightning Test Swept Continuous Wave Data Plots



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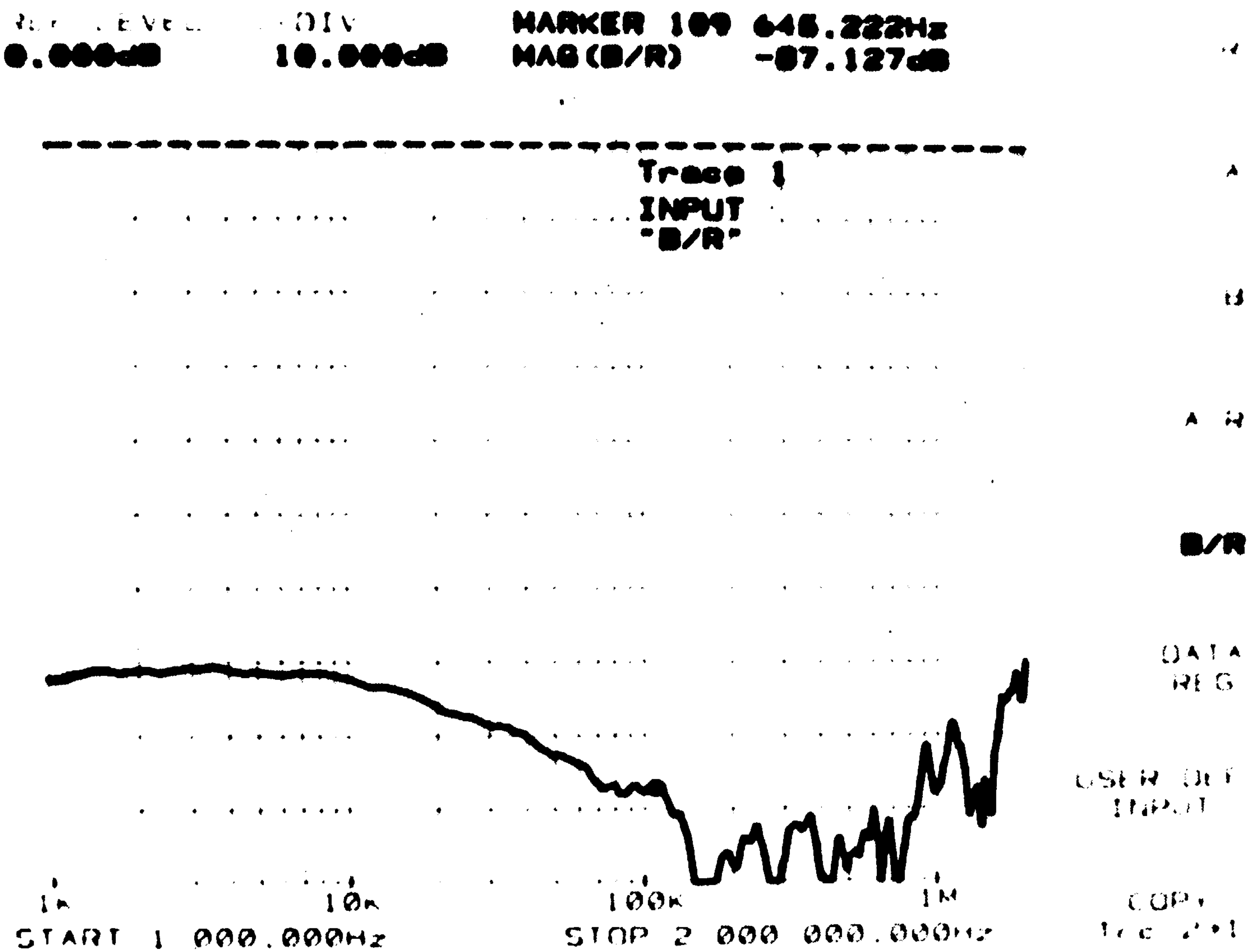
Swept Continuous Wave #1, Injection (add 18dB)



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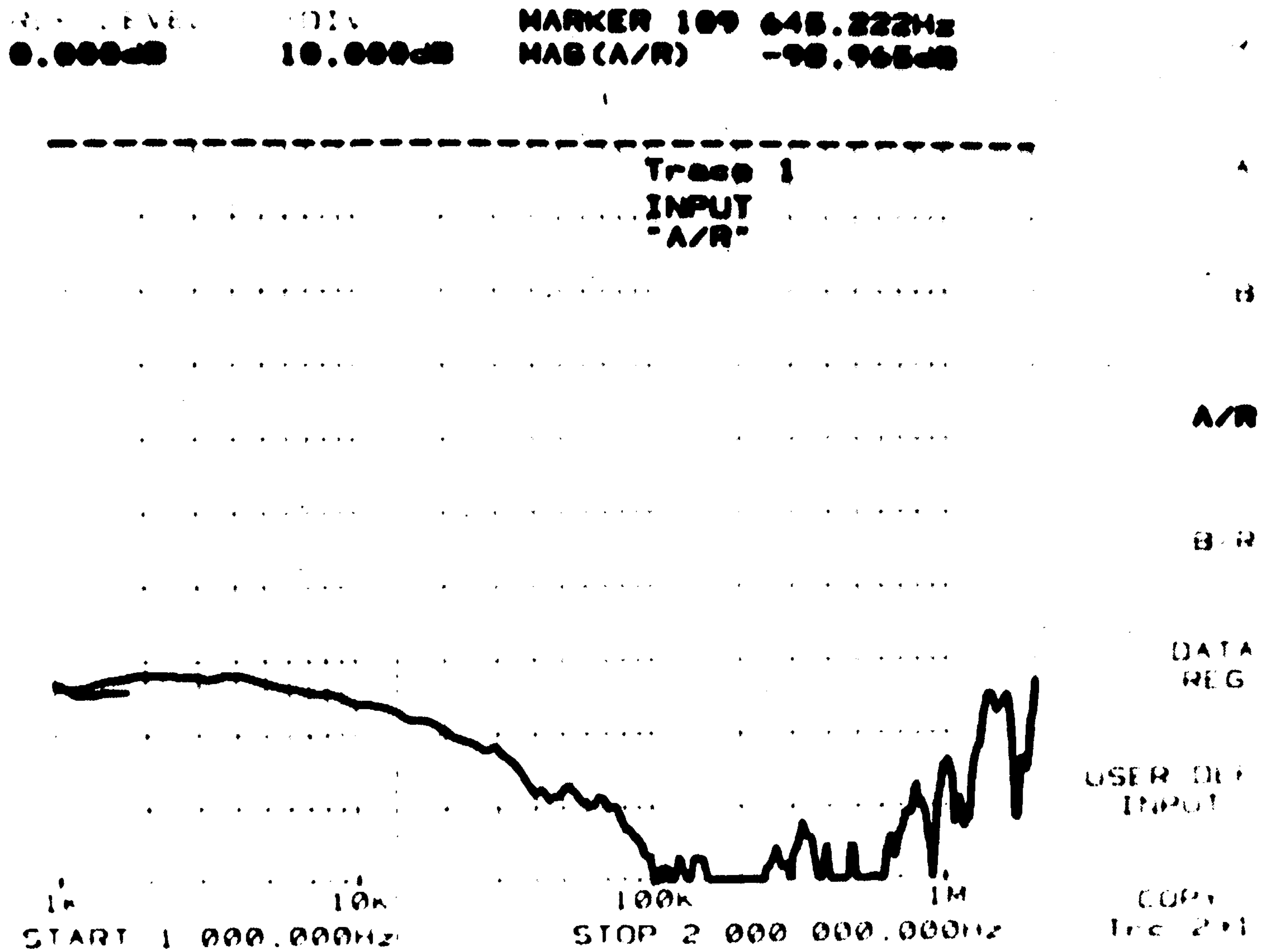
Swept Continuous Wave #2, Noise Measurement of Forward Break-Out-Box
From 1 KHz to 2 MHz (subtract 18 dB)



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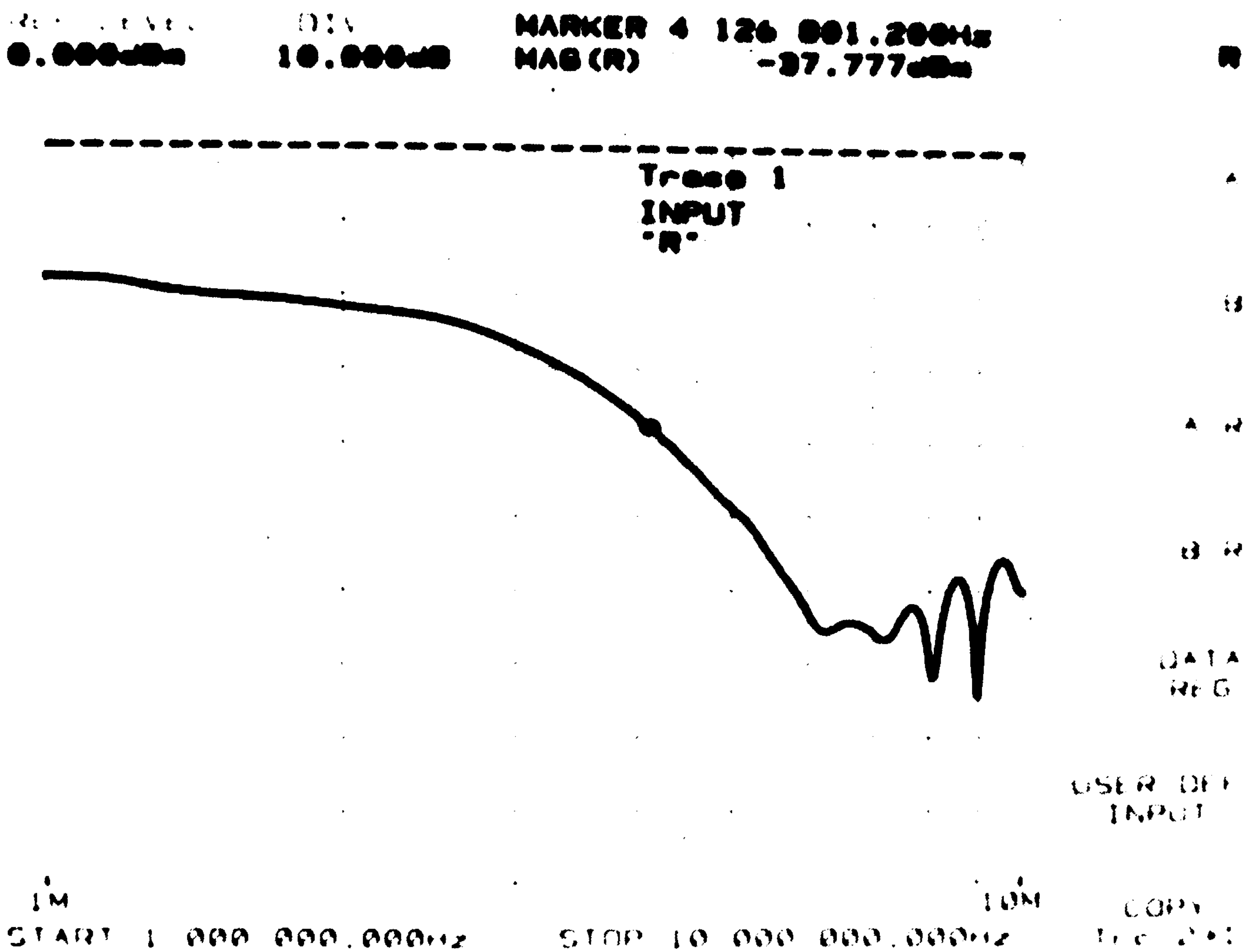
Swept Continuous Wave #3, Noise Measurement of Aft Break-Out-Box
From 1 KHz to 2 MHz (subtract 18 dB)



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Swept Continuous Wave #4, Injection (add 18 dB)

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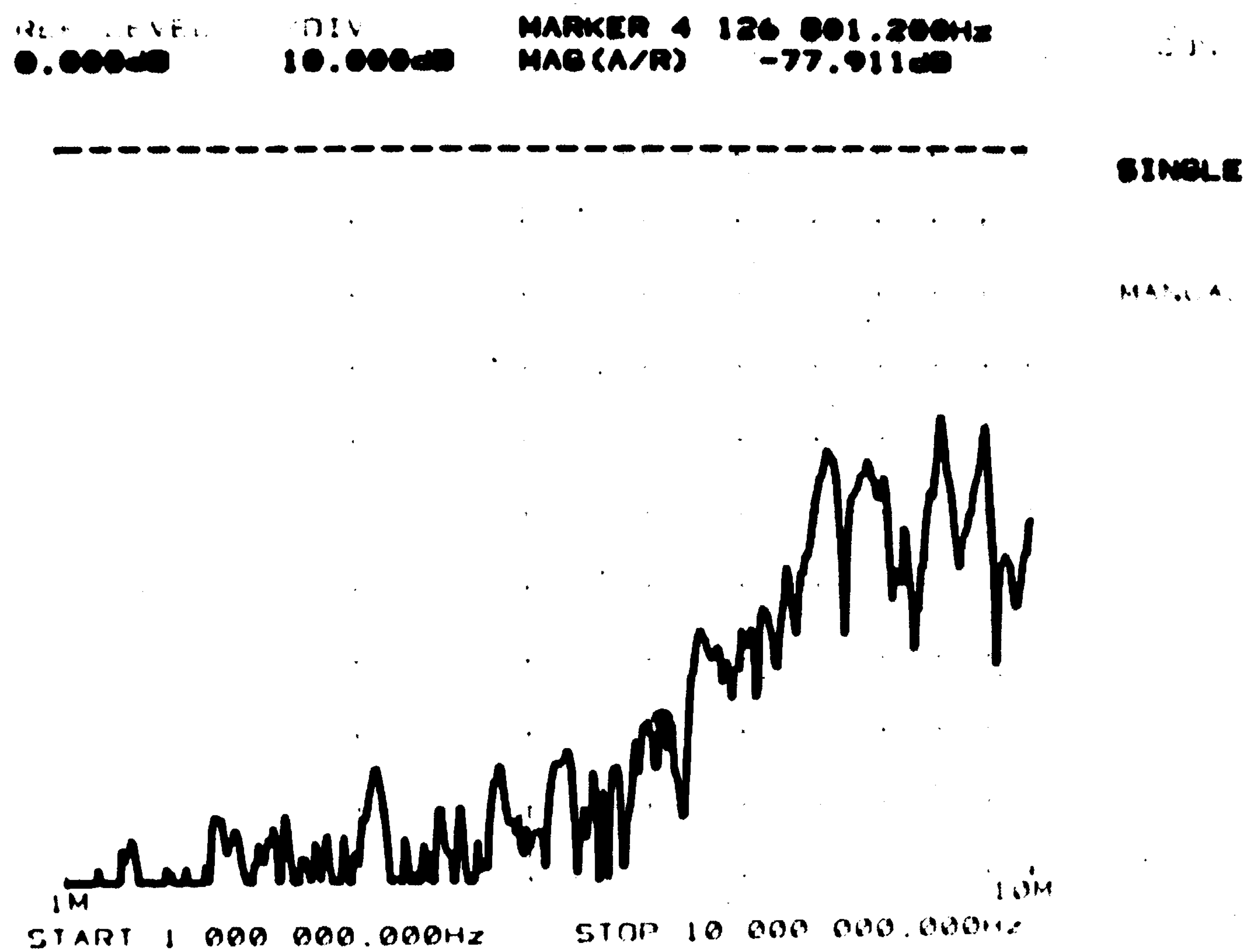

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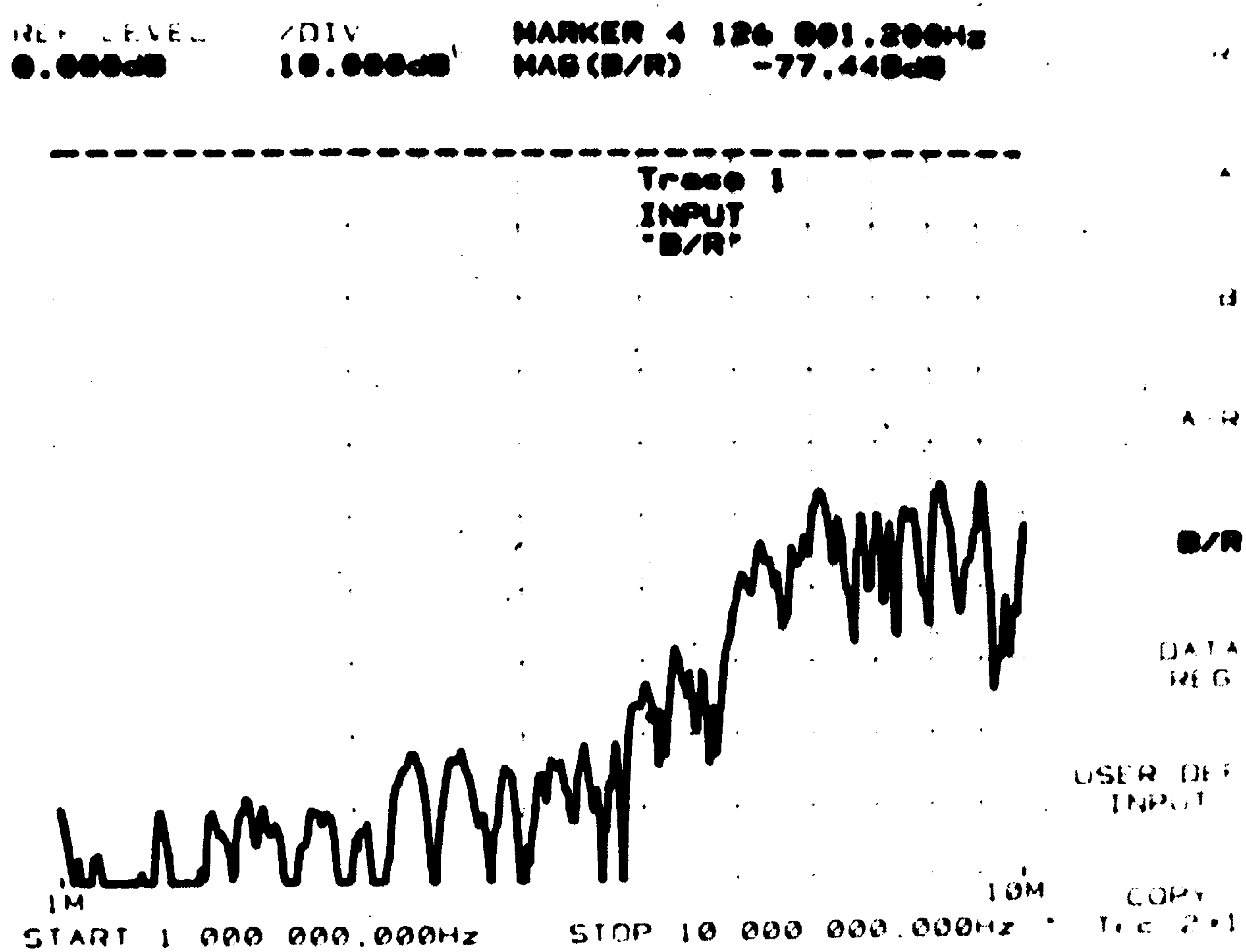
Swept Continuous Wave #5, Noise Measurement of Forward Break-Out-Box
From 1 MHz to 10 MHz (subtract 18 dB)



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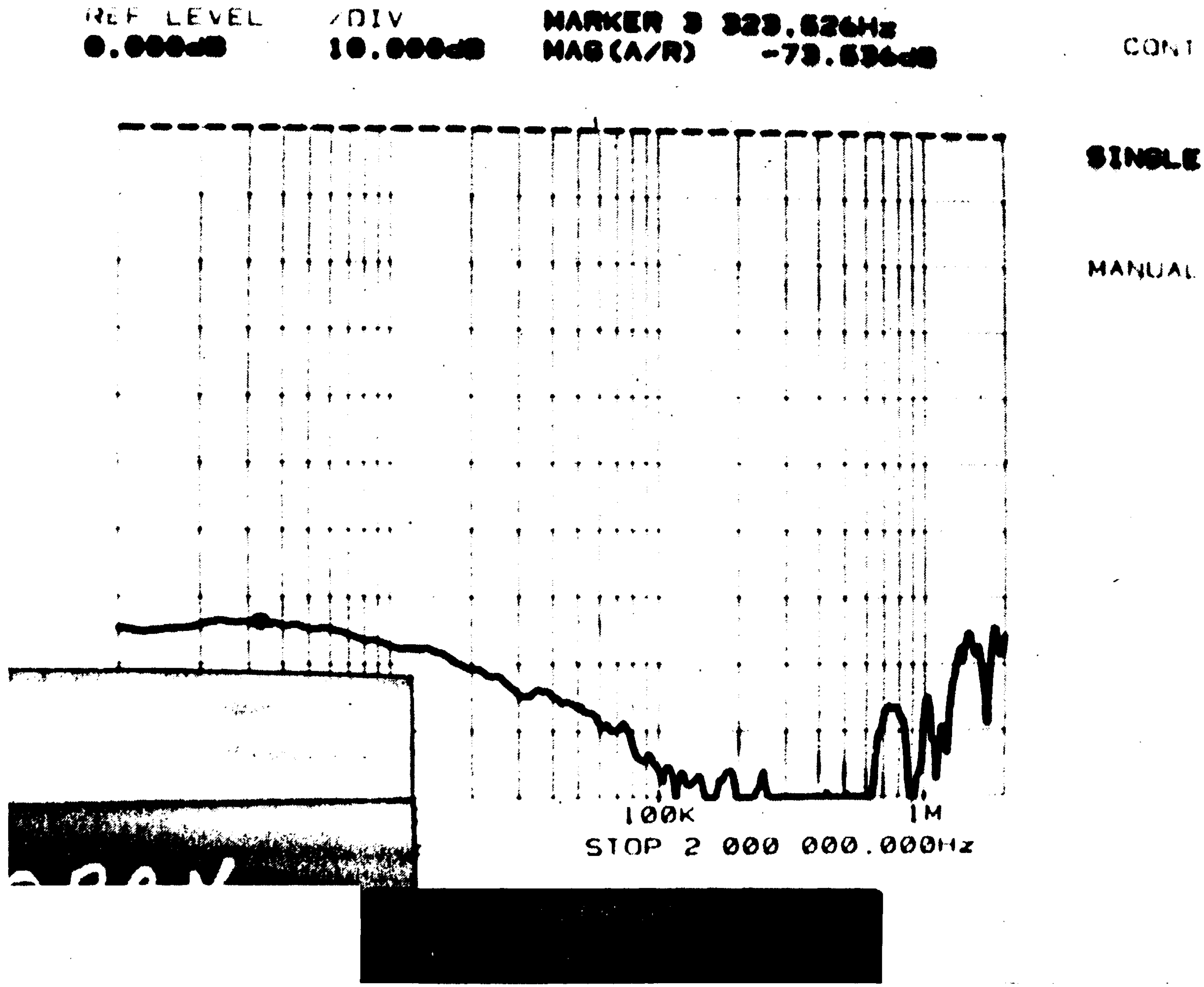
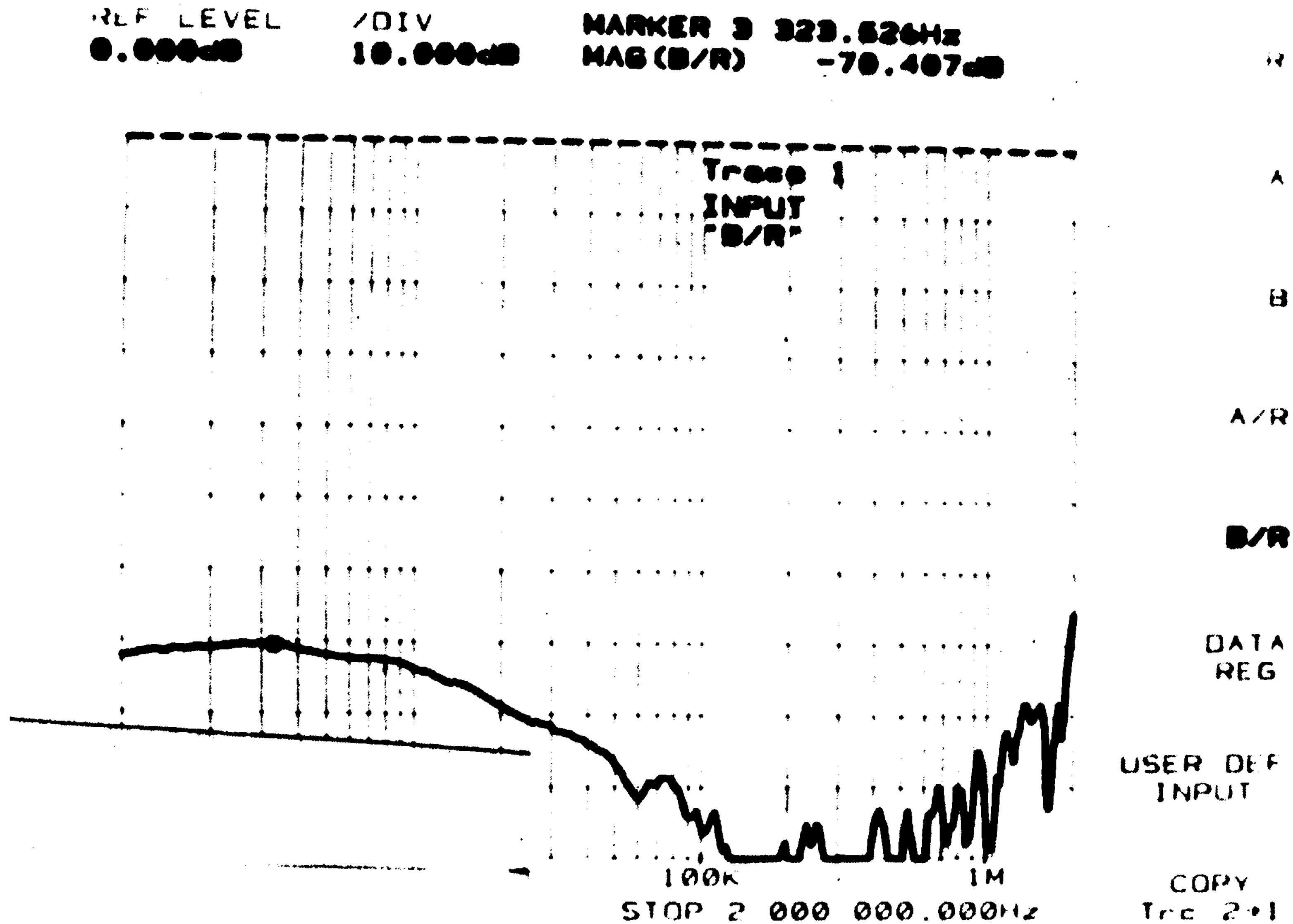
Swept Continuous Wave #6, Noise Measurement of Aft Break-Out-Box
From 1 MHz to 10 MHz (subtract 18 dB)



Swept Continuous Wave #7, Attach point #1, Cable #8, Open circuit voltage, EMI shields closed (subtract 18 dB)



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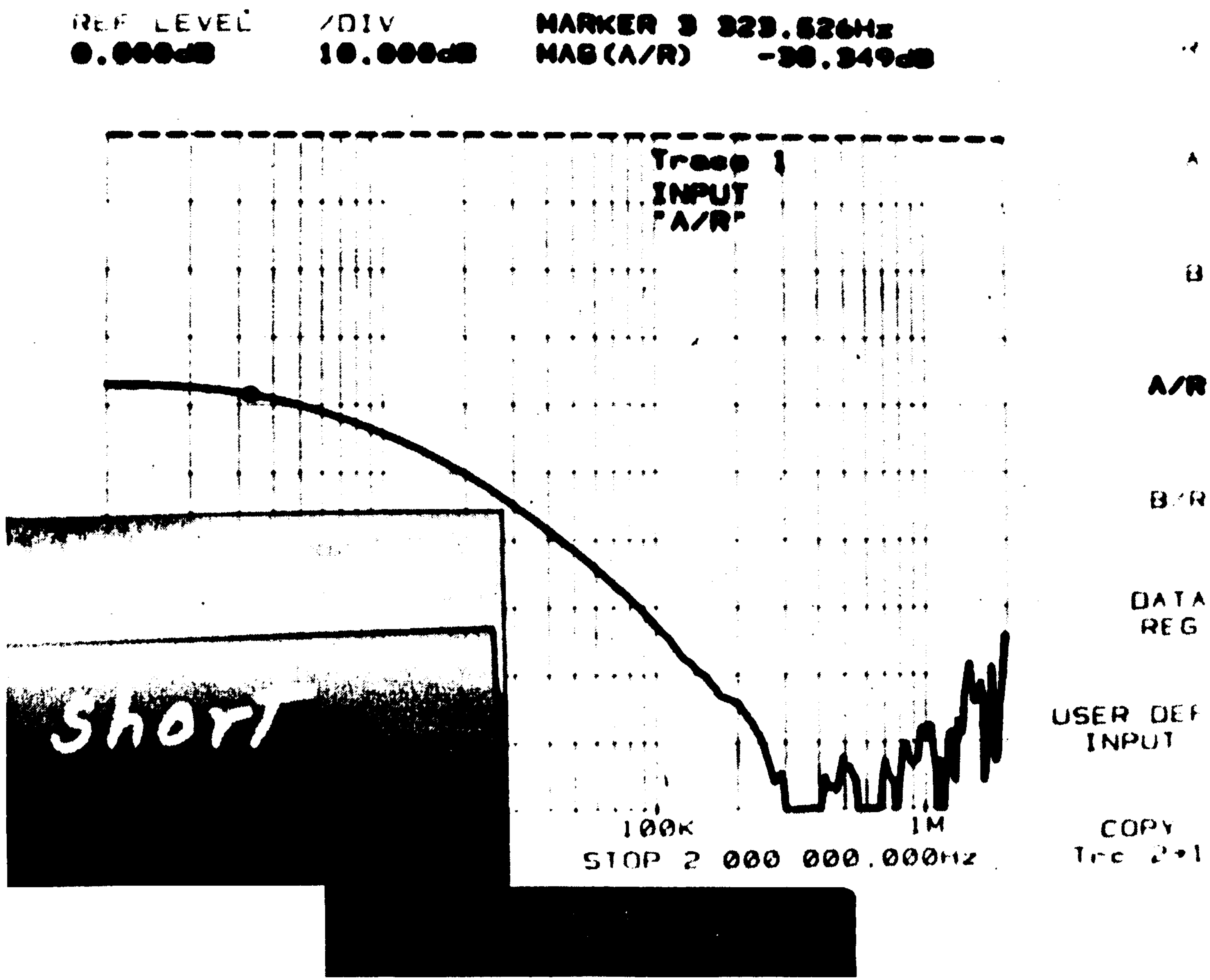
Swept Continuous Wave #8, Attach point #1, Cable #10, Open circuit voltage, EMI shields closed (subtract 18 dB)



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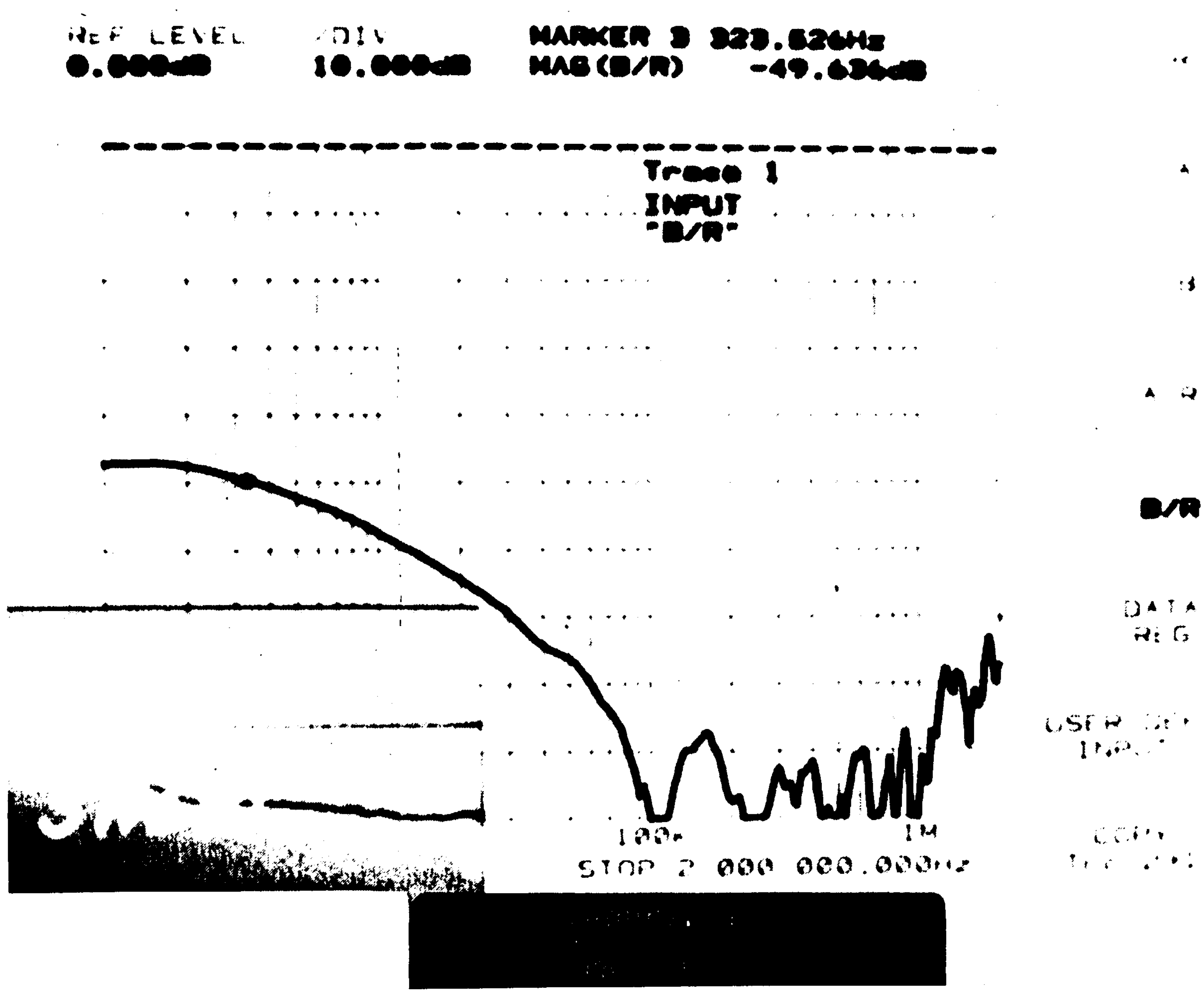

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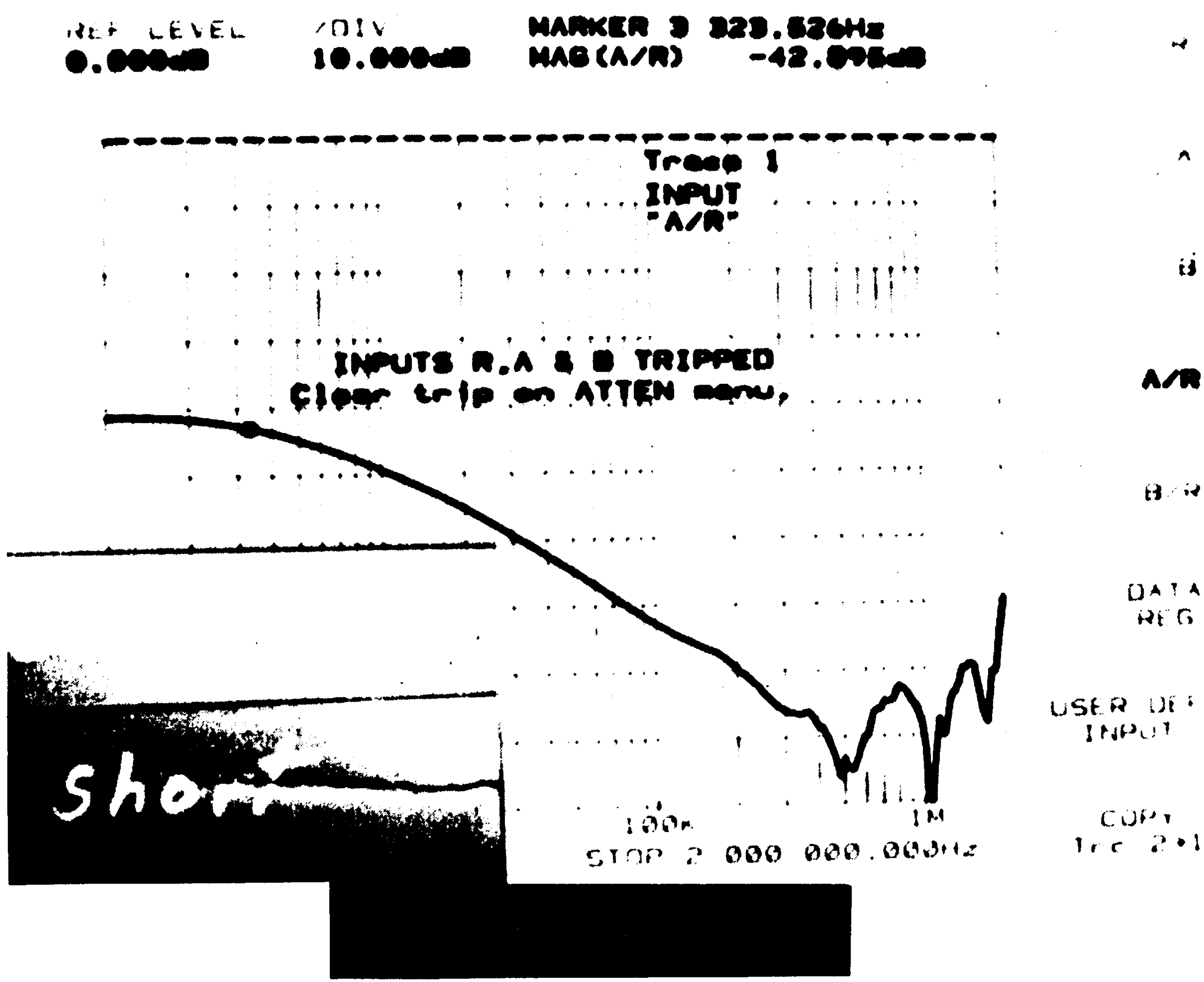

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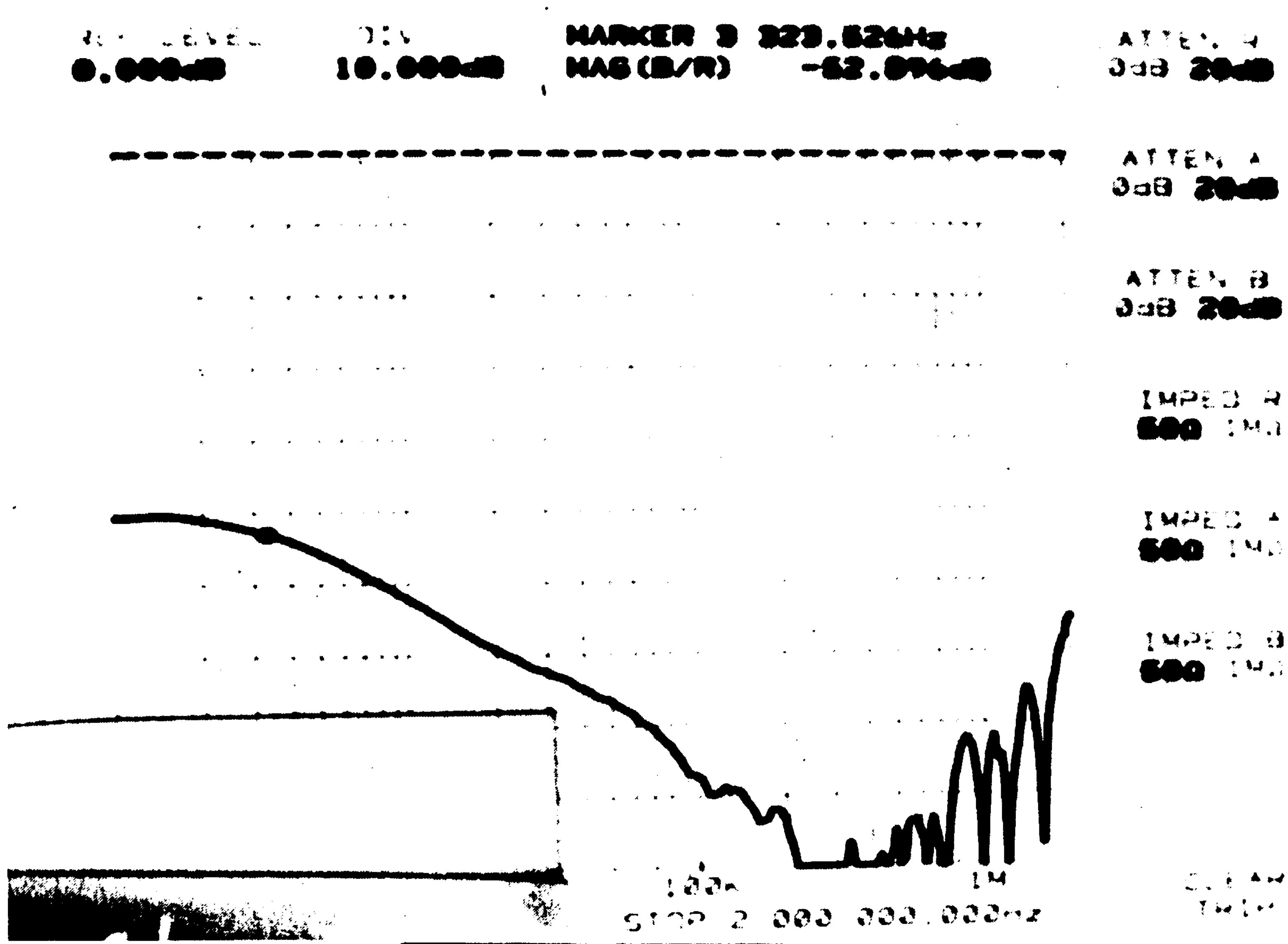

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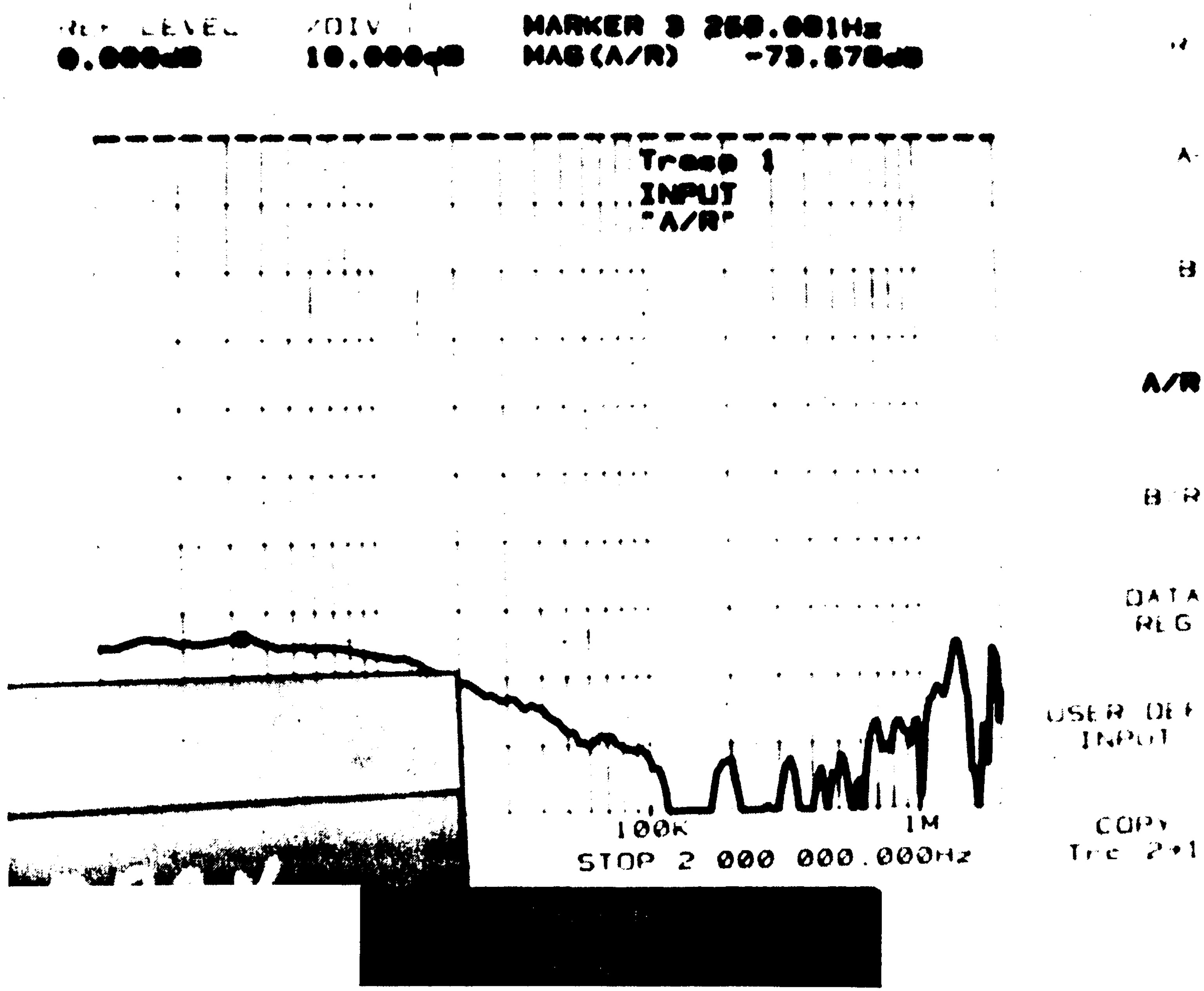
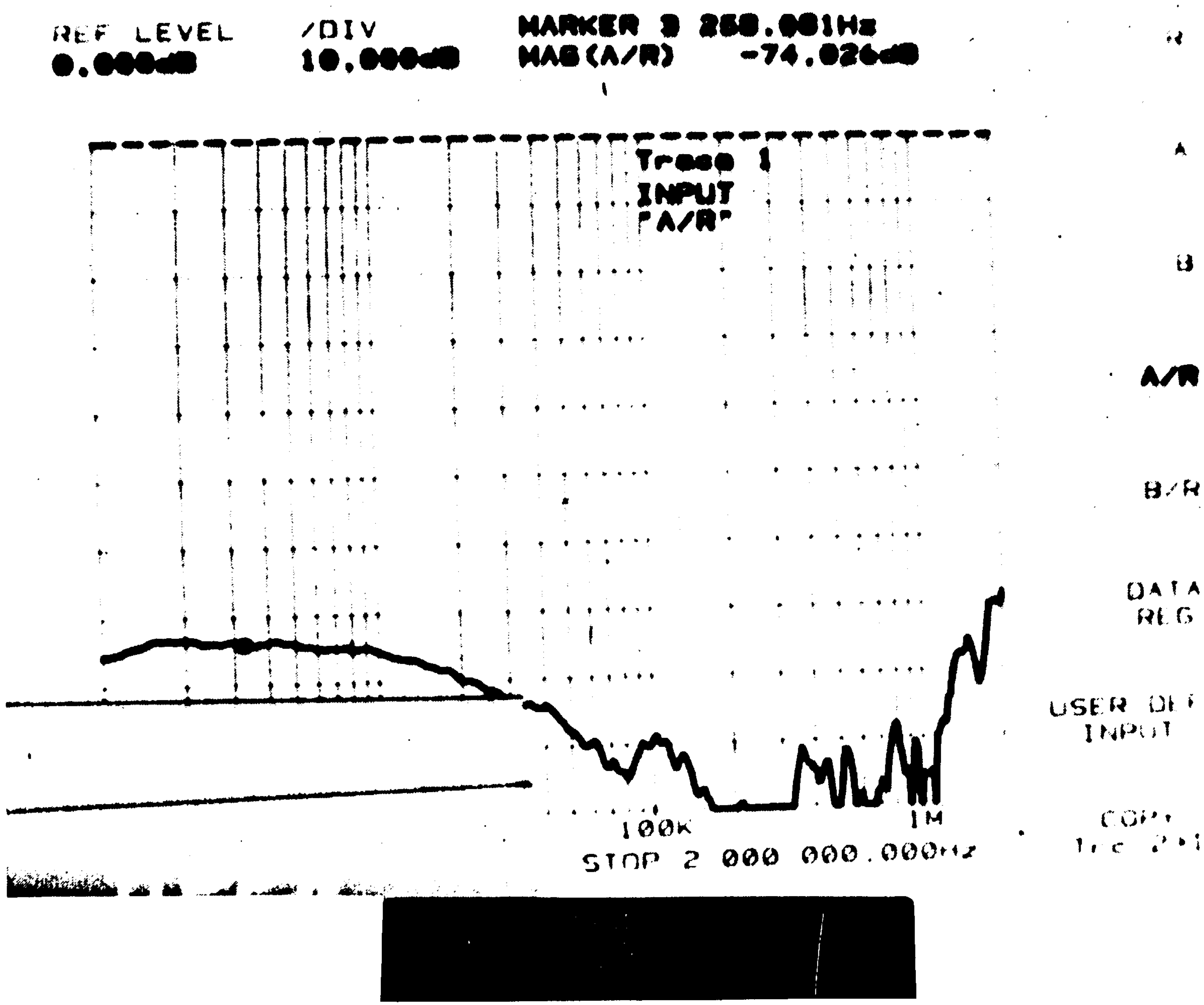
Swept Continuous Wave #12, Attach point #1, Cable #12, Short circuit current, EMI shields closed (subtract 18 dB)



Swept Continuous Wave #13, Attach point #1, Cable #6, Open circuit voltage, EMI shields closed (subtract 18 dB)



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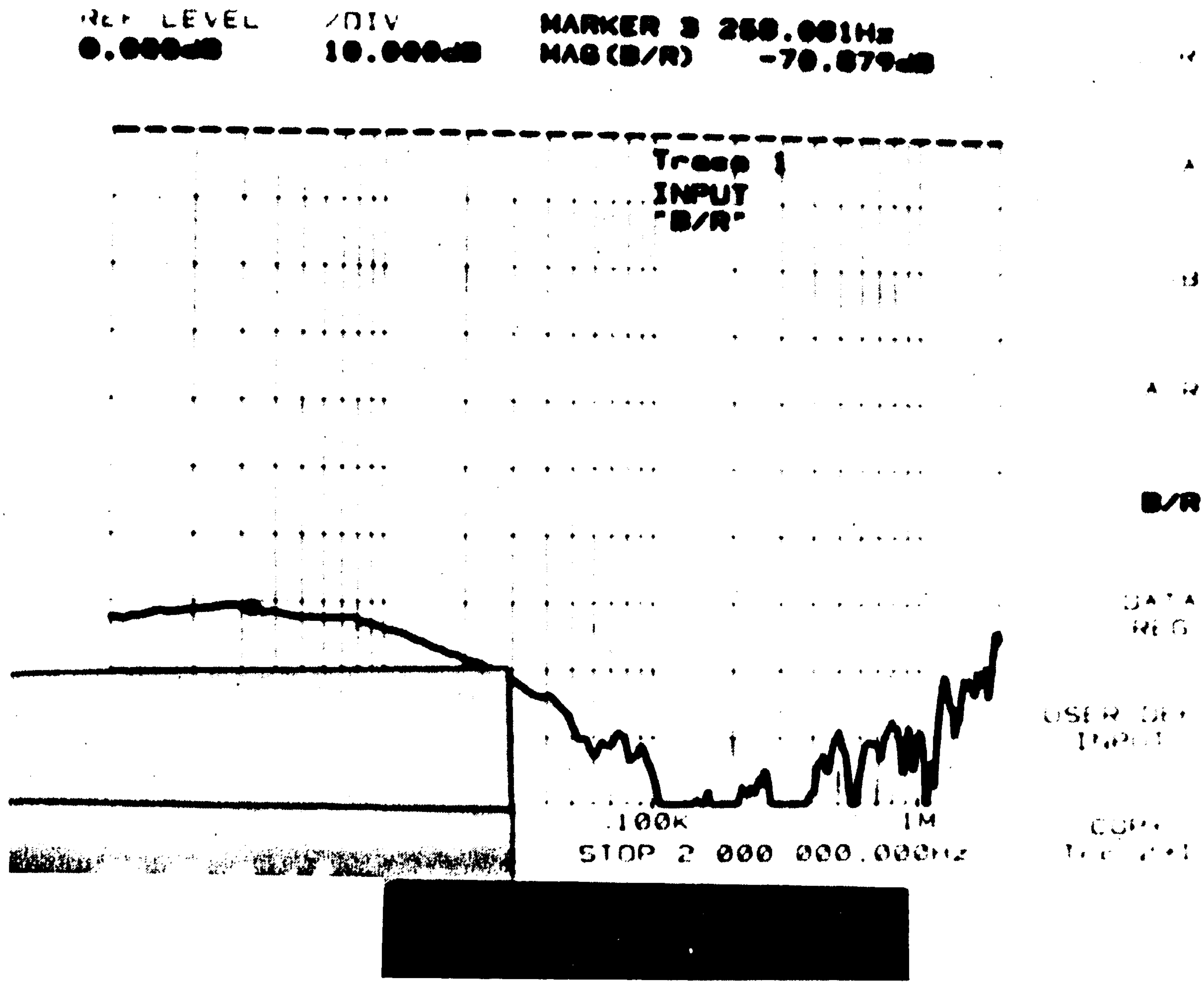

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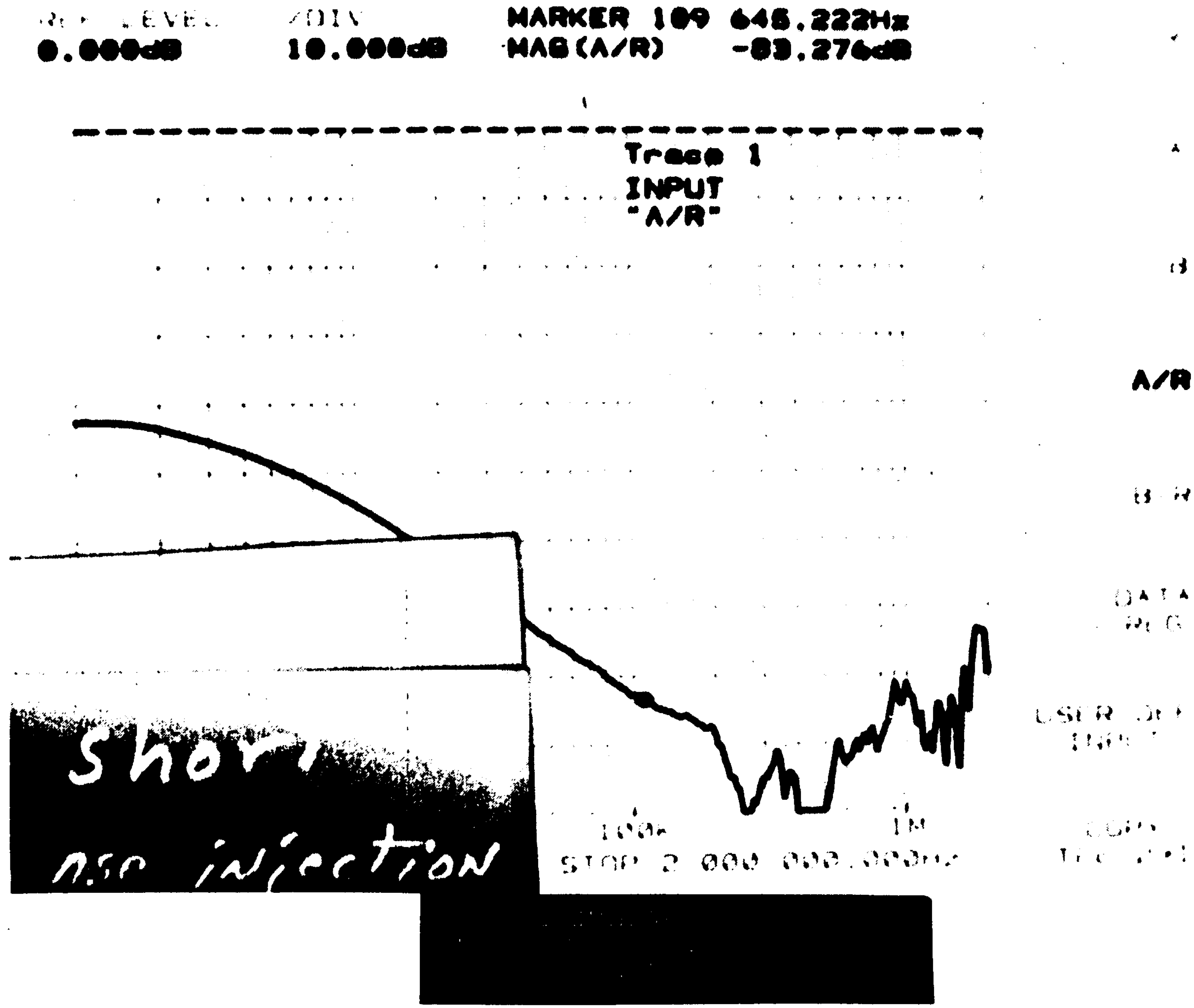

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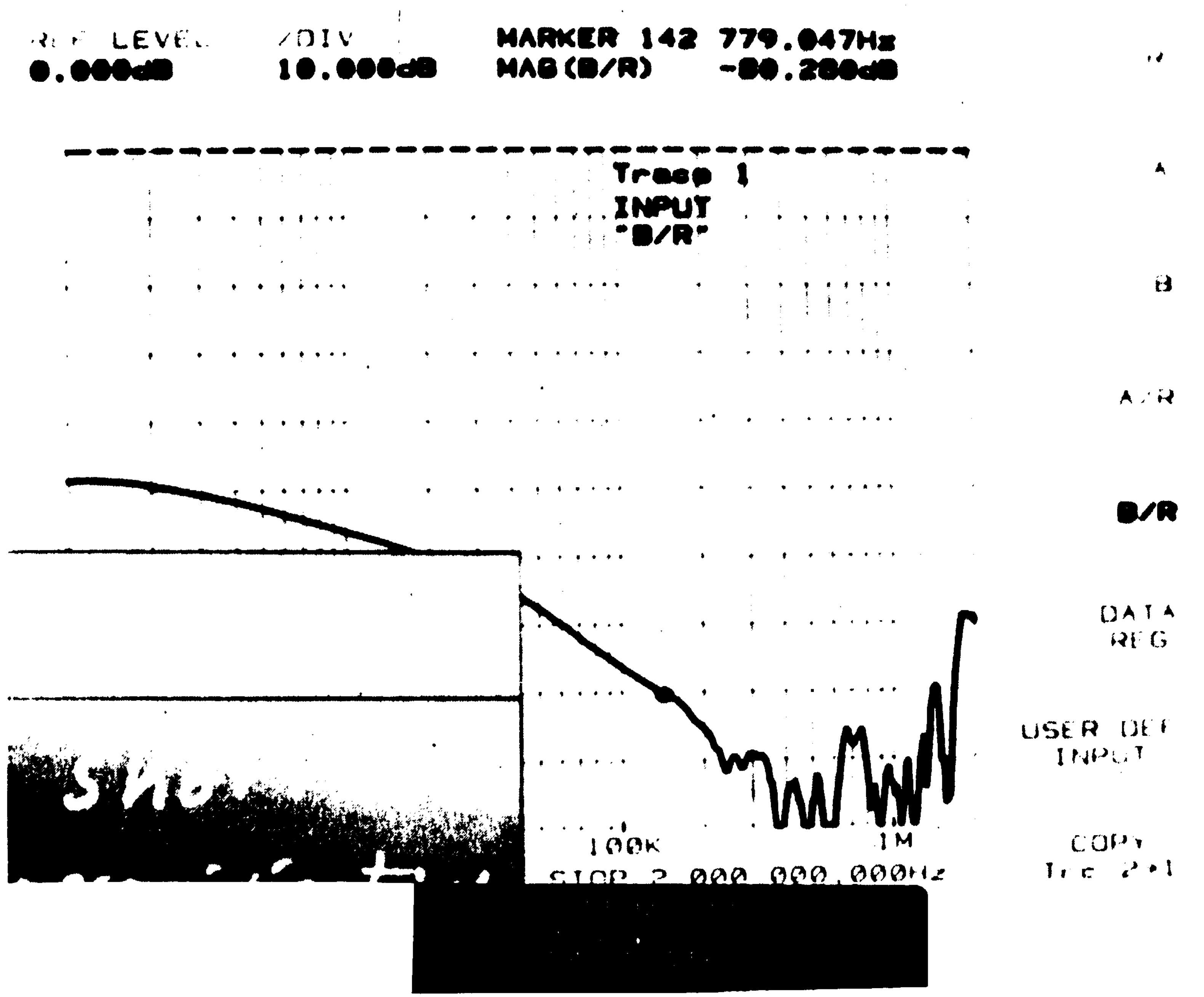

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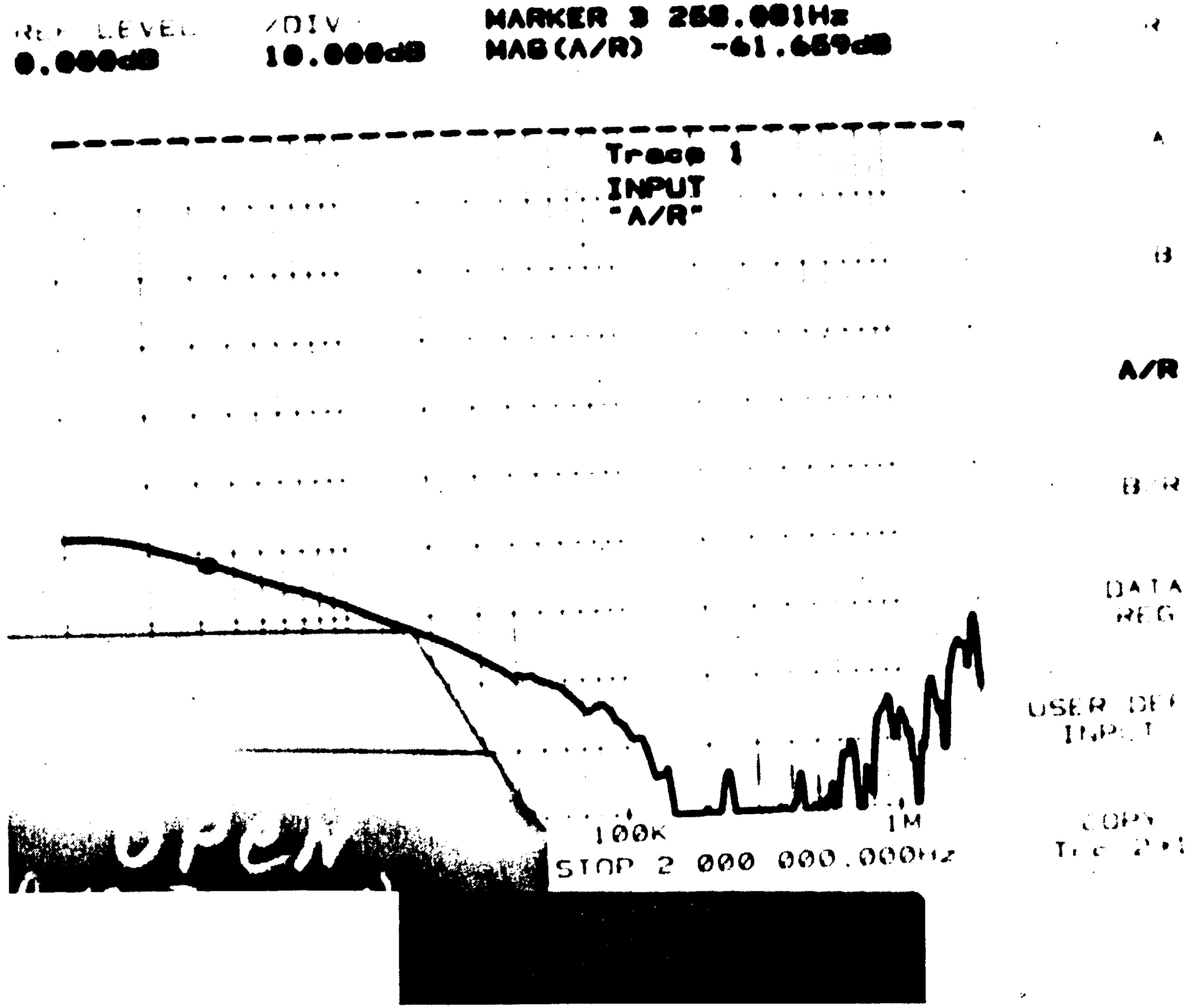

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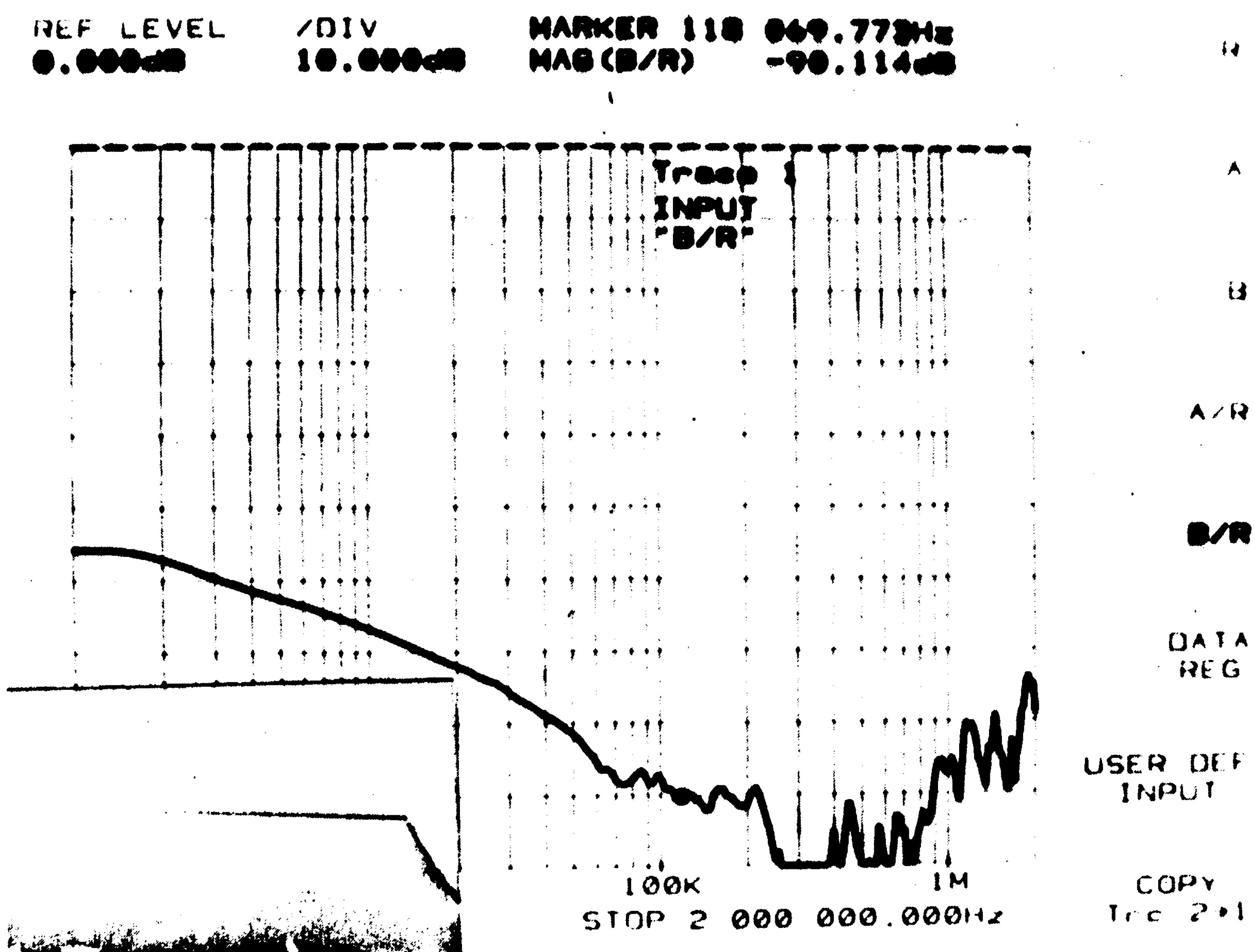

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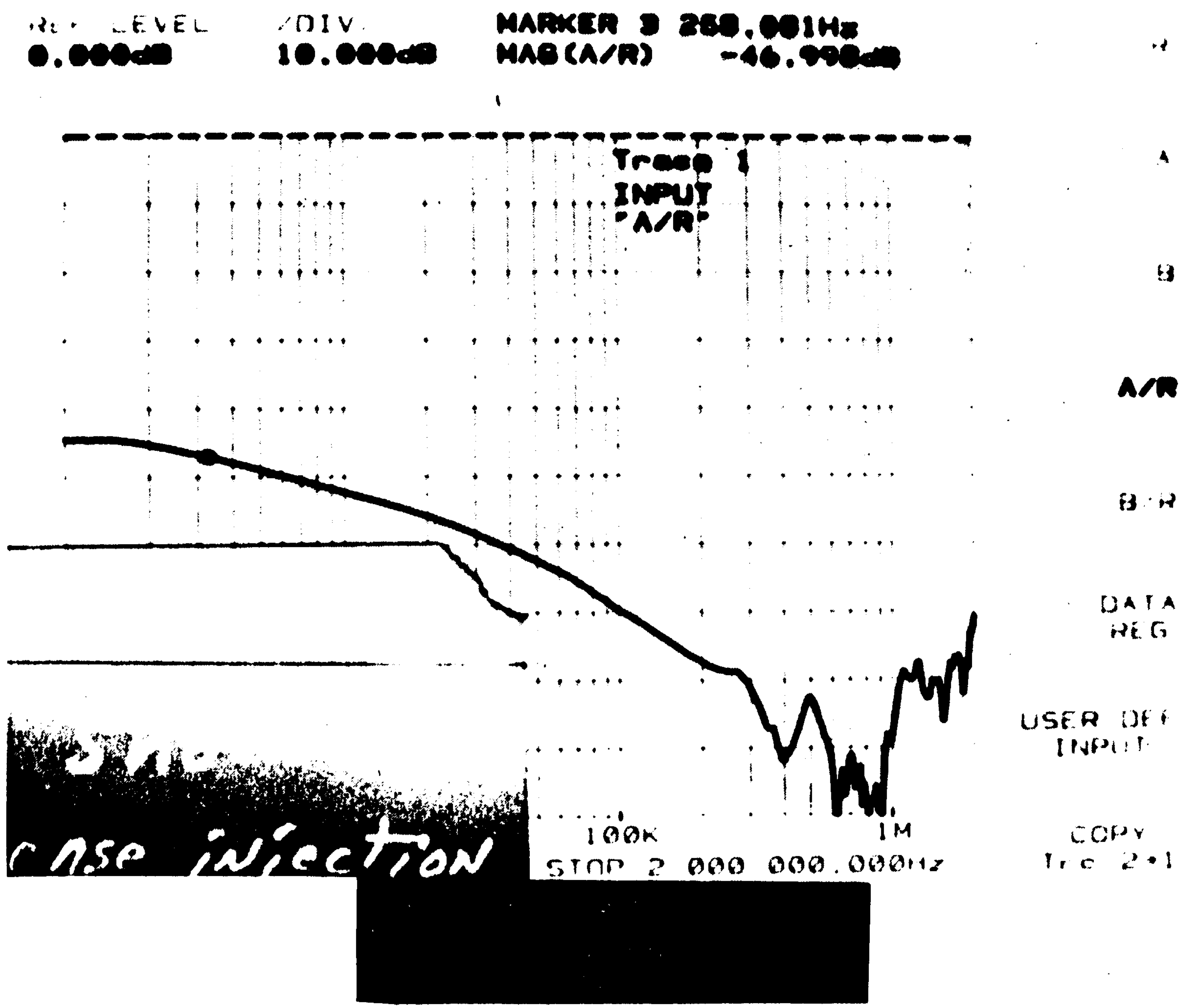

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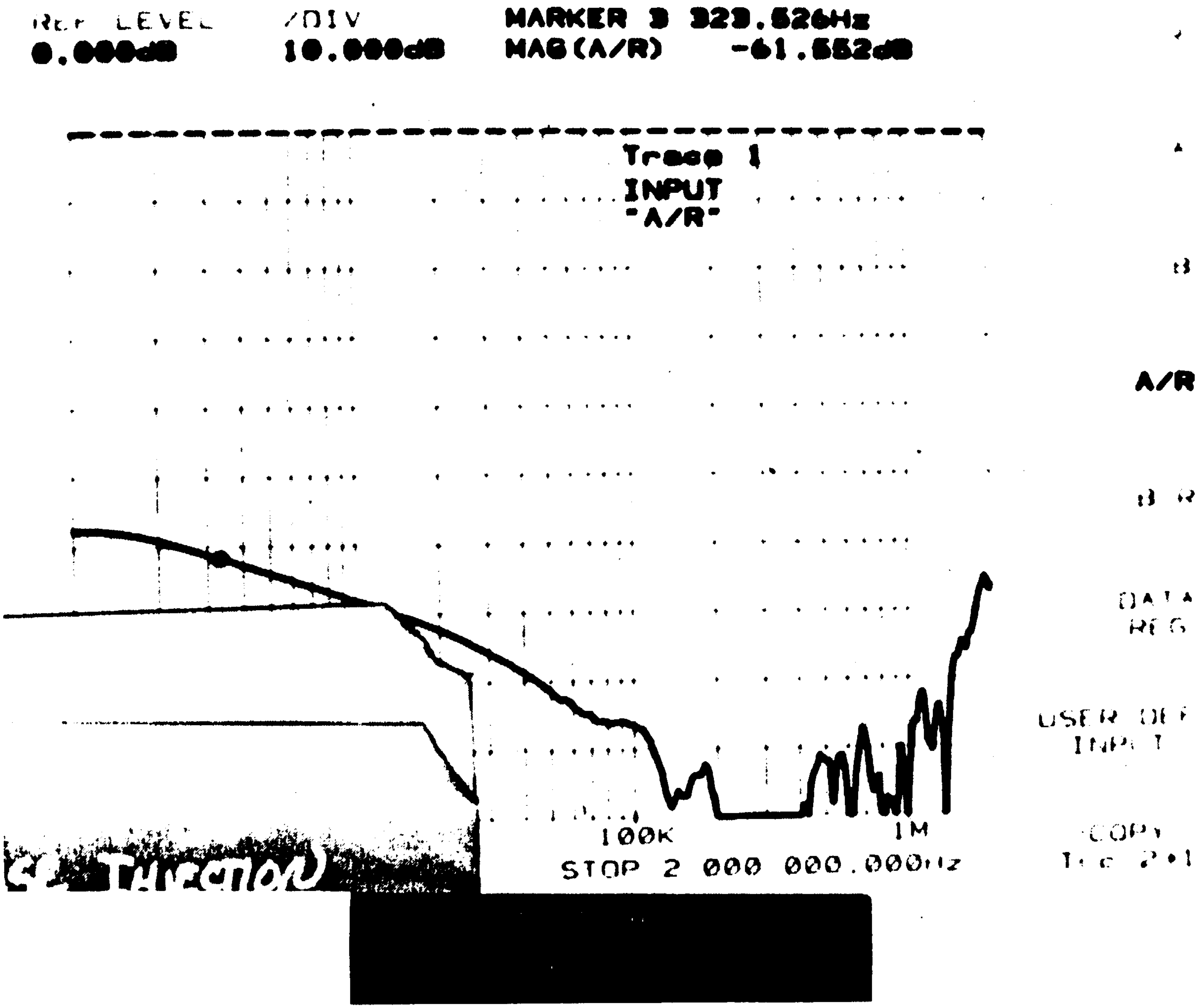

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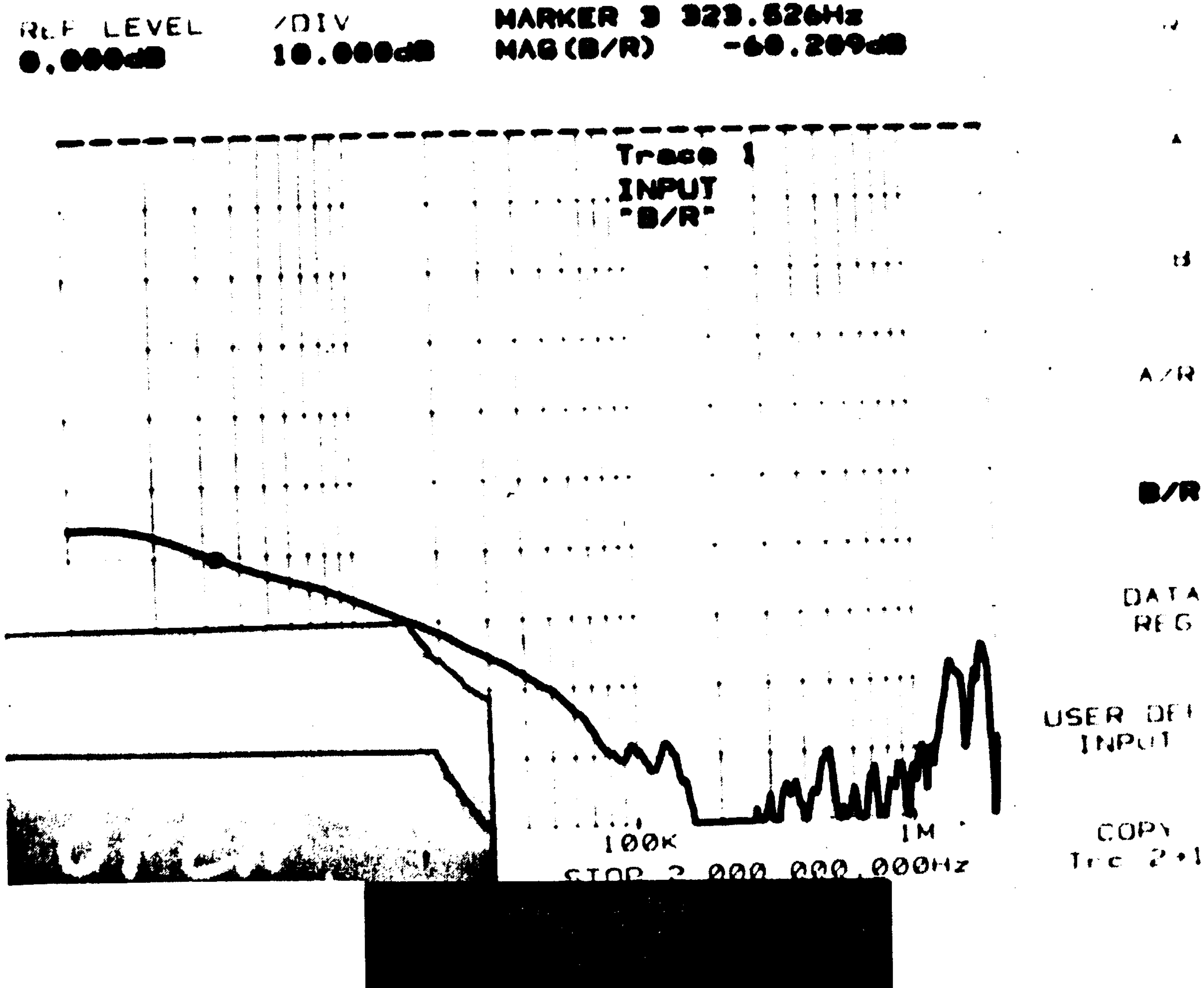

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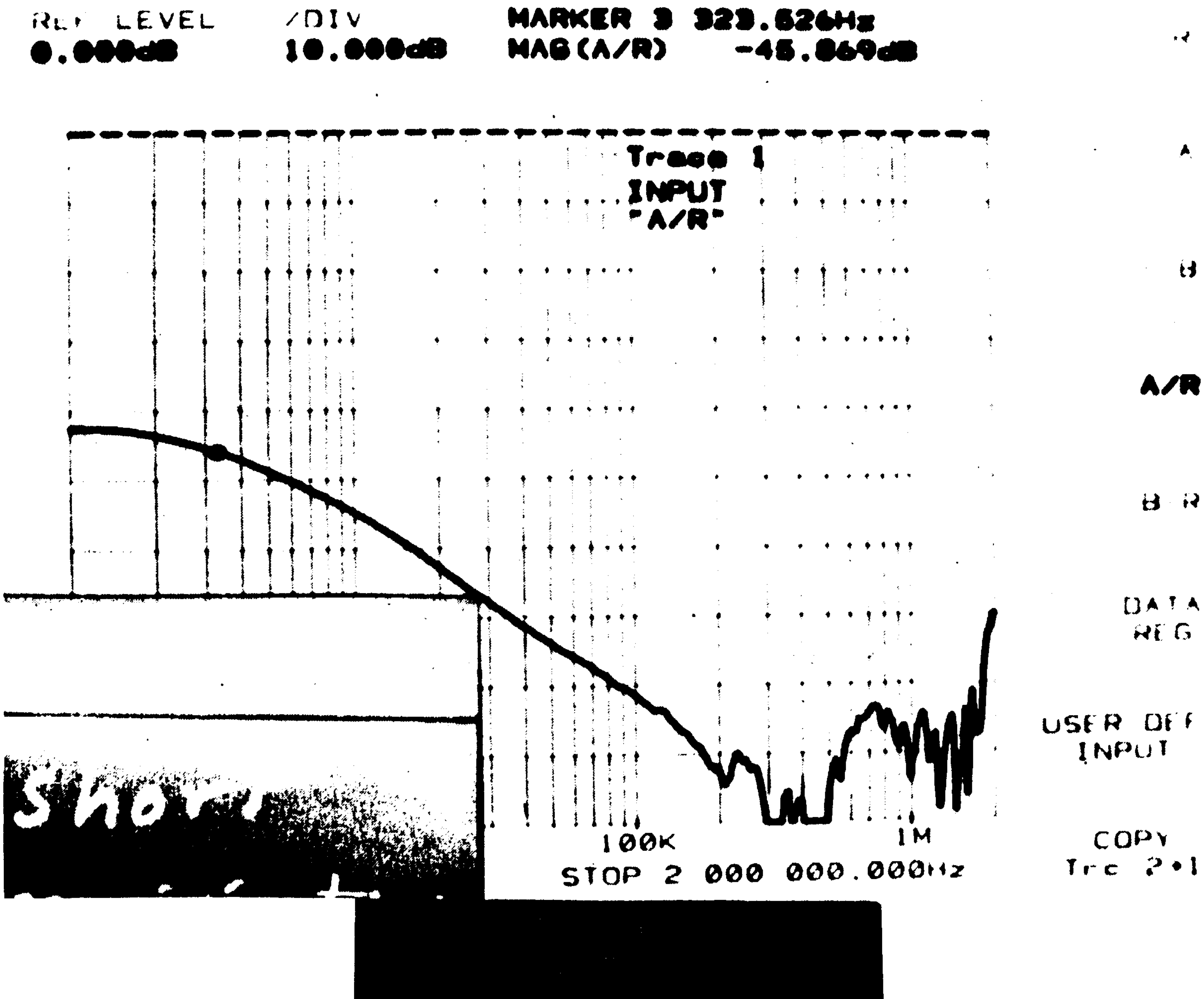
Swept Continuous Wave #26, Attach point #3, Cable #12, Open circuit voltage, EMI shields closed (subtract 18 dB)



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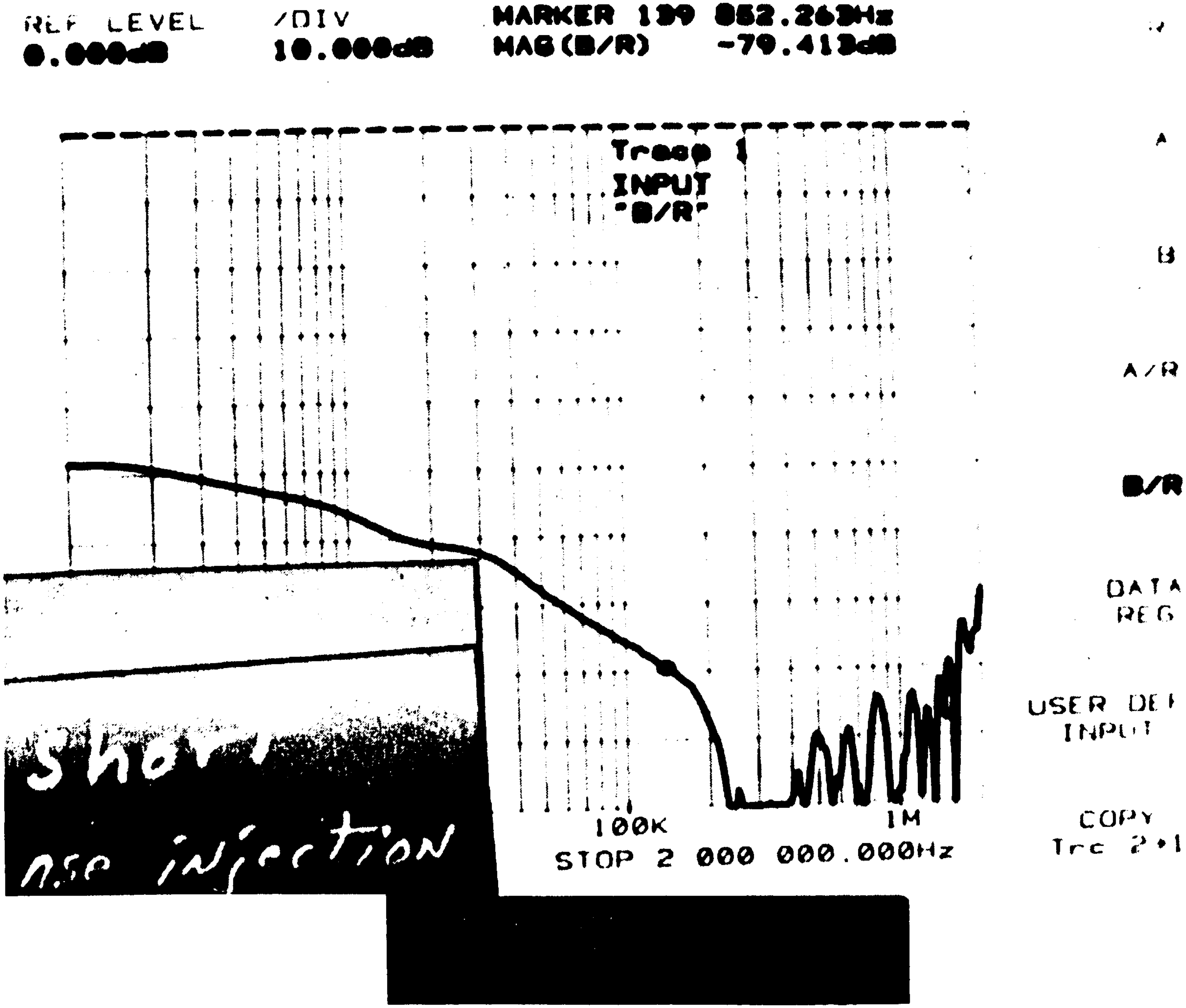
Swept Continuous Wave #27, Attach point #3, Cable #8, Short circuit current, EMI shields closed (subtract 18 dB)



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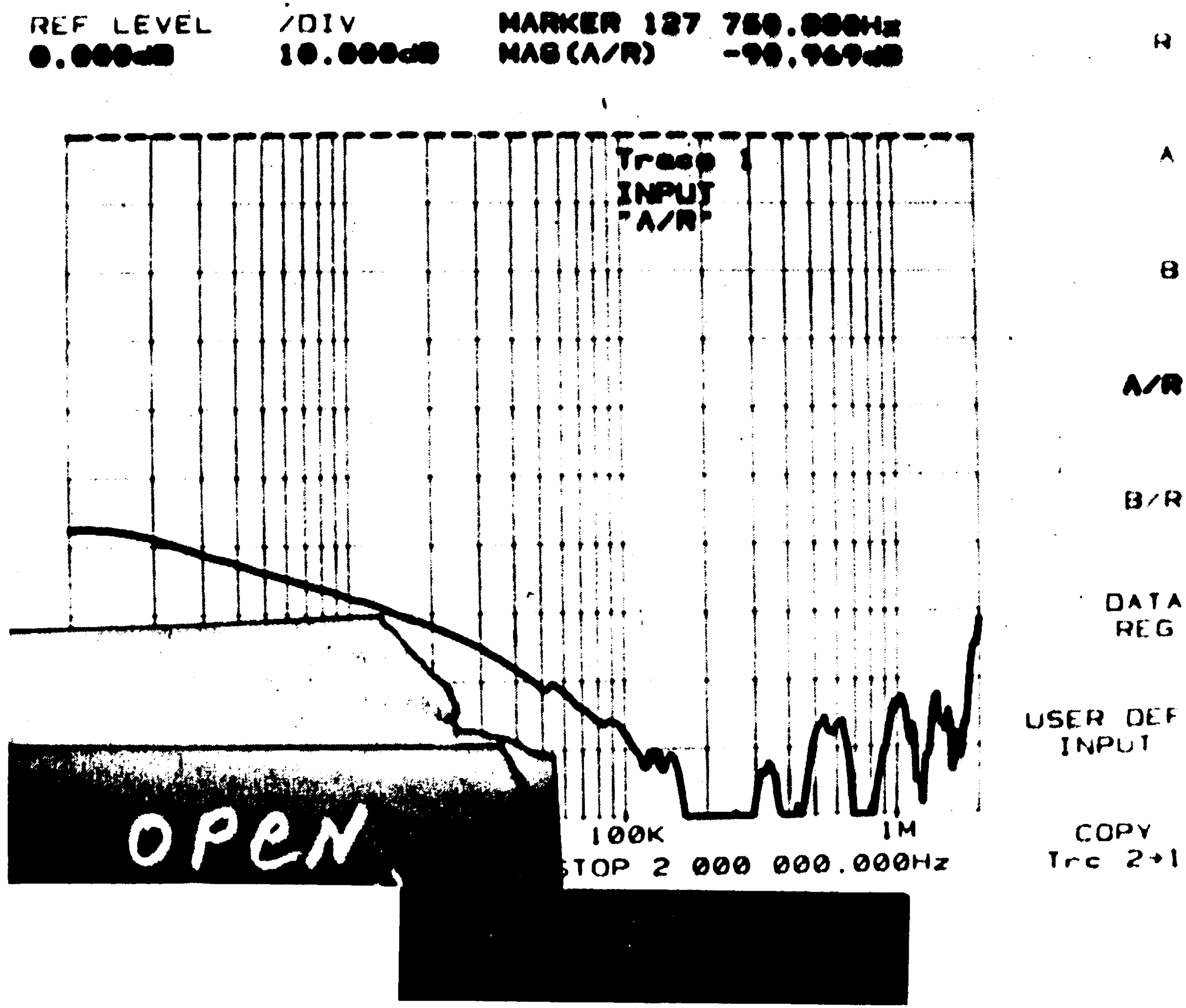
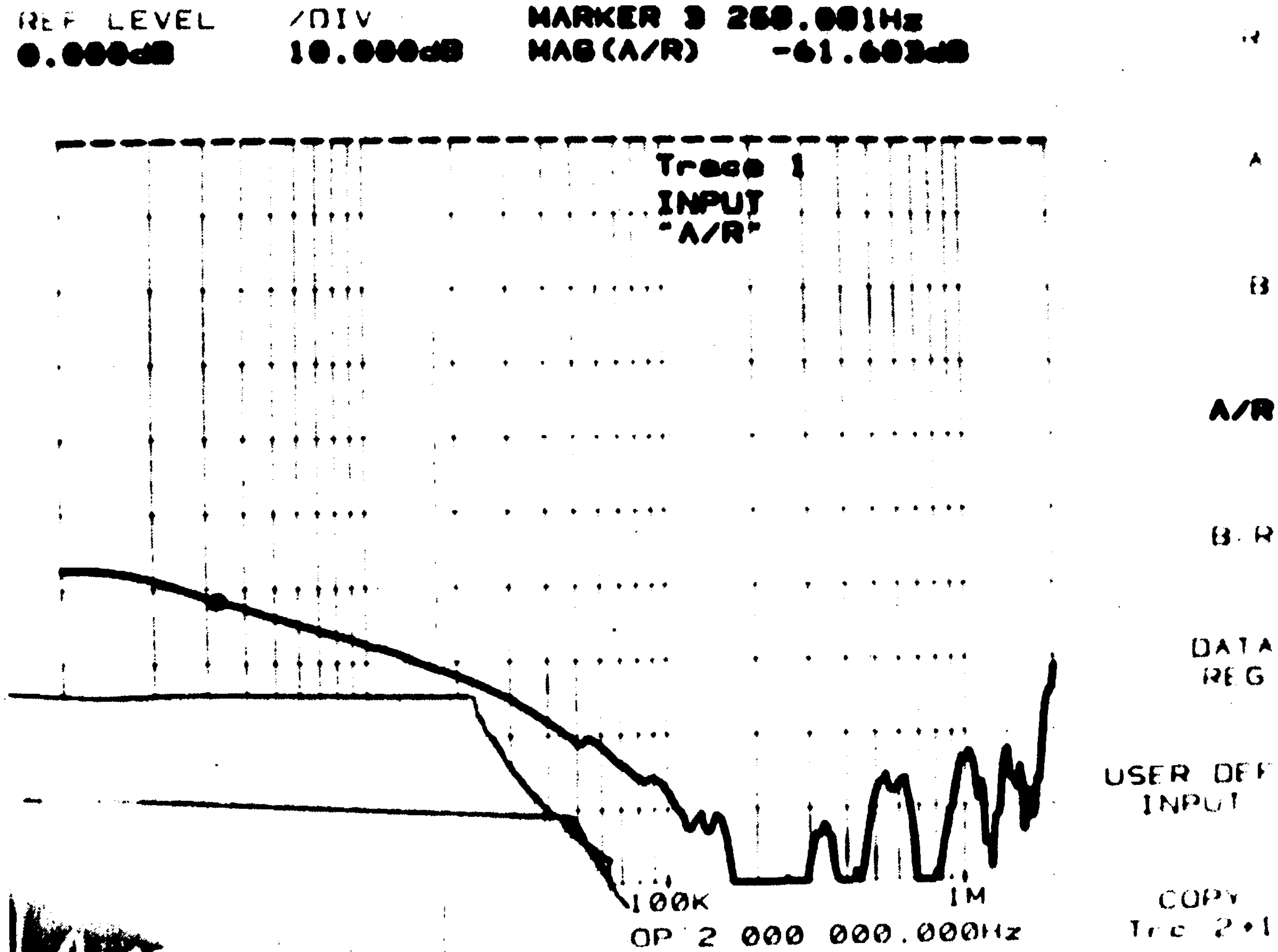


Swept Continuous Wave #29, Attach point #3, Cable #8, Open circuit voltage, EMI shields closed (subtract 18 dB)



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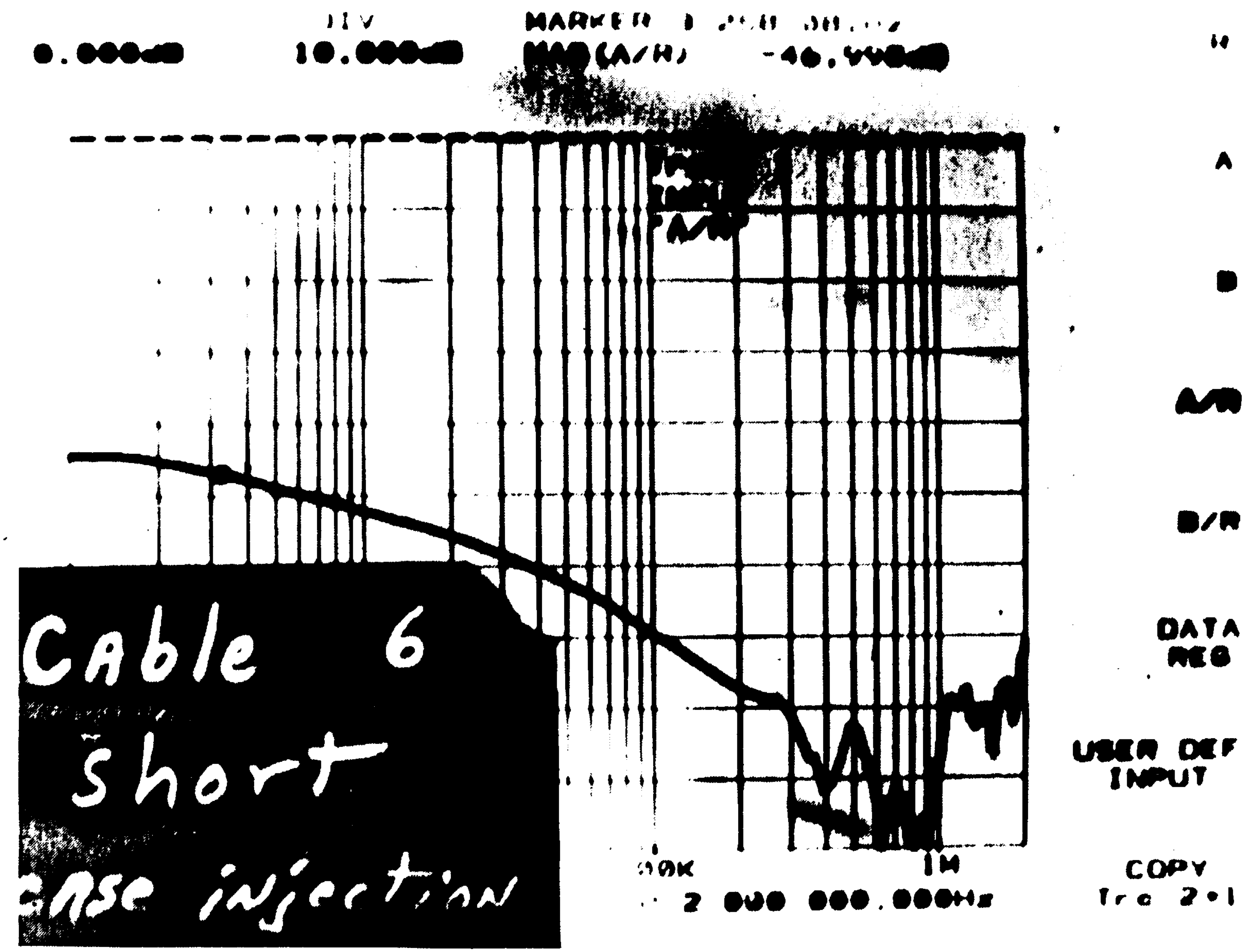
Swept Continuous Wave #30, Attach point #3, Cable #10, Open circuit voltage, EMI shields closed (subtract 18 dB)



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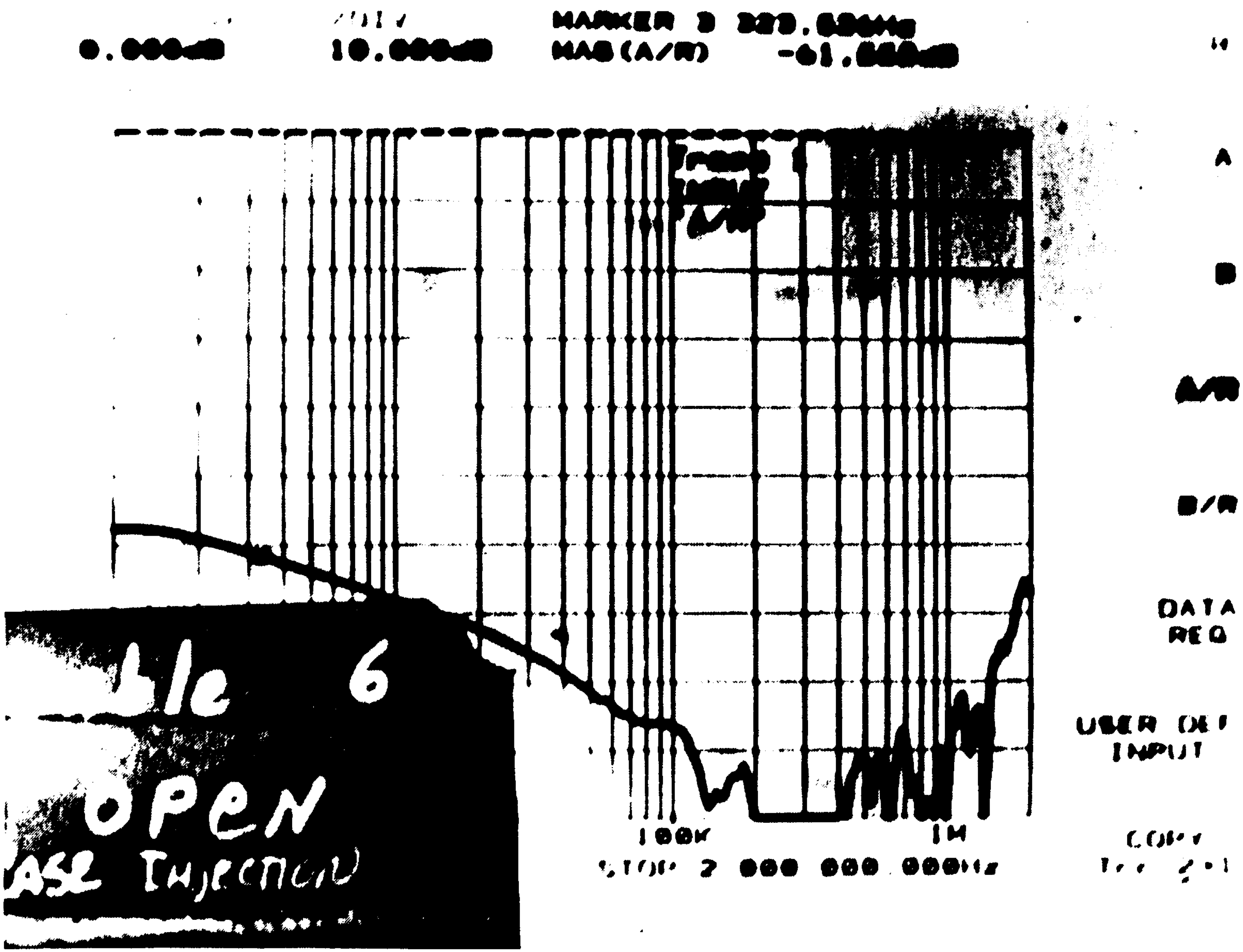

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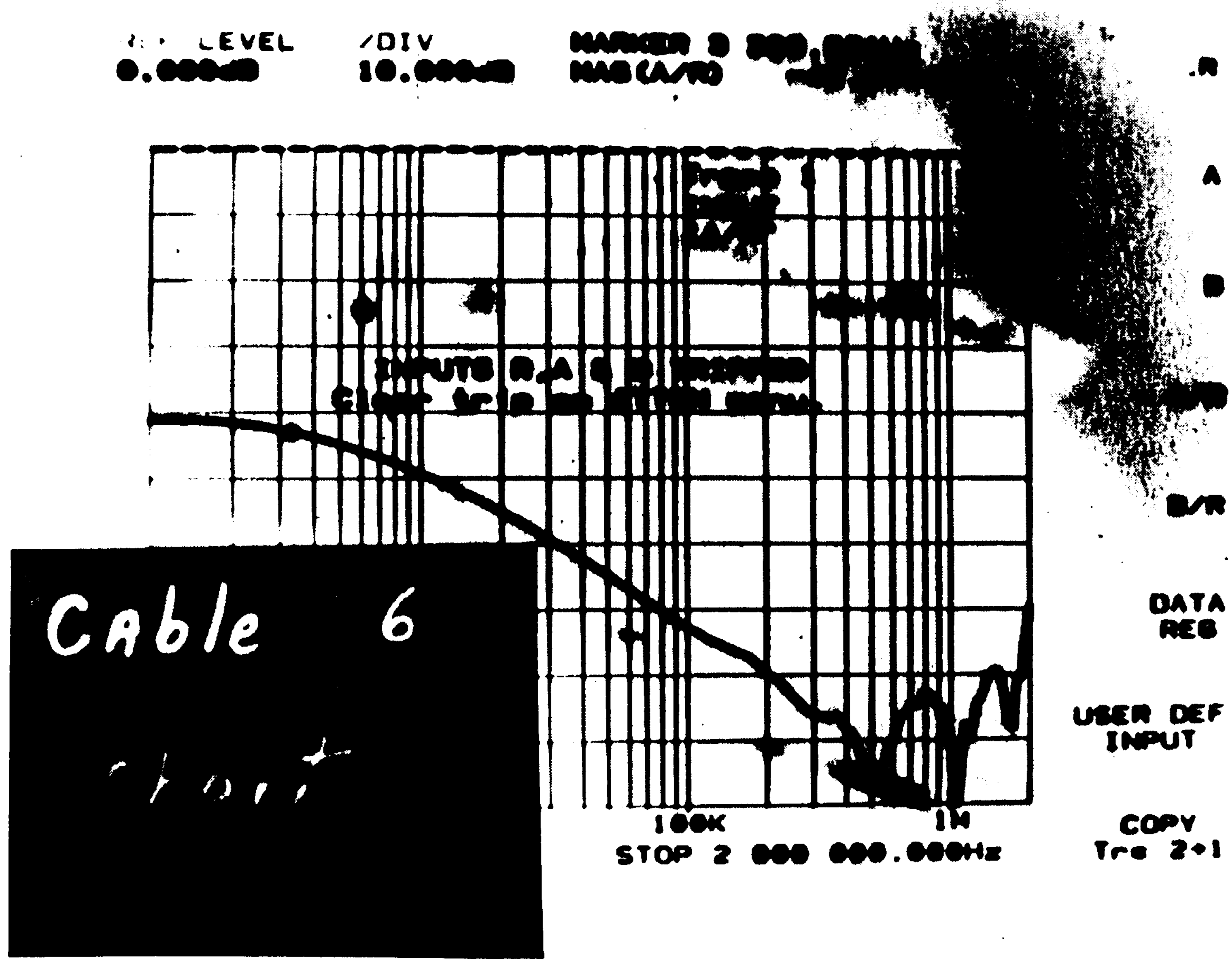

Swept Continuous Wave #33, Attach point: station 703, Cable #6, Short circuit current, EMI shields closed (subtract 18 dB)

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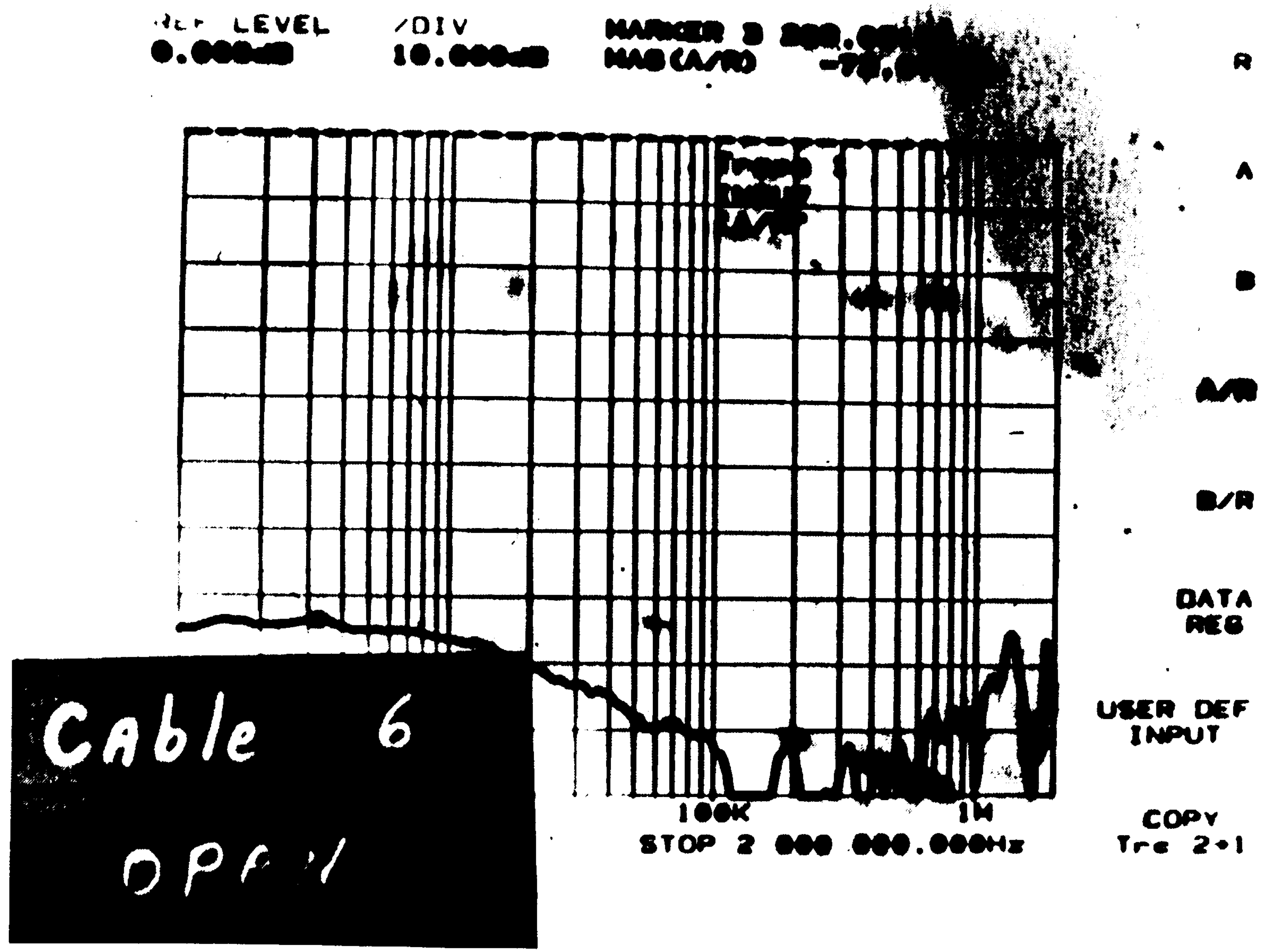

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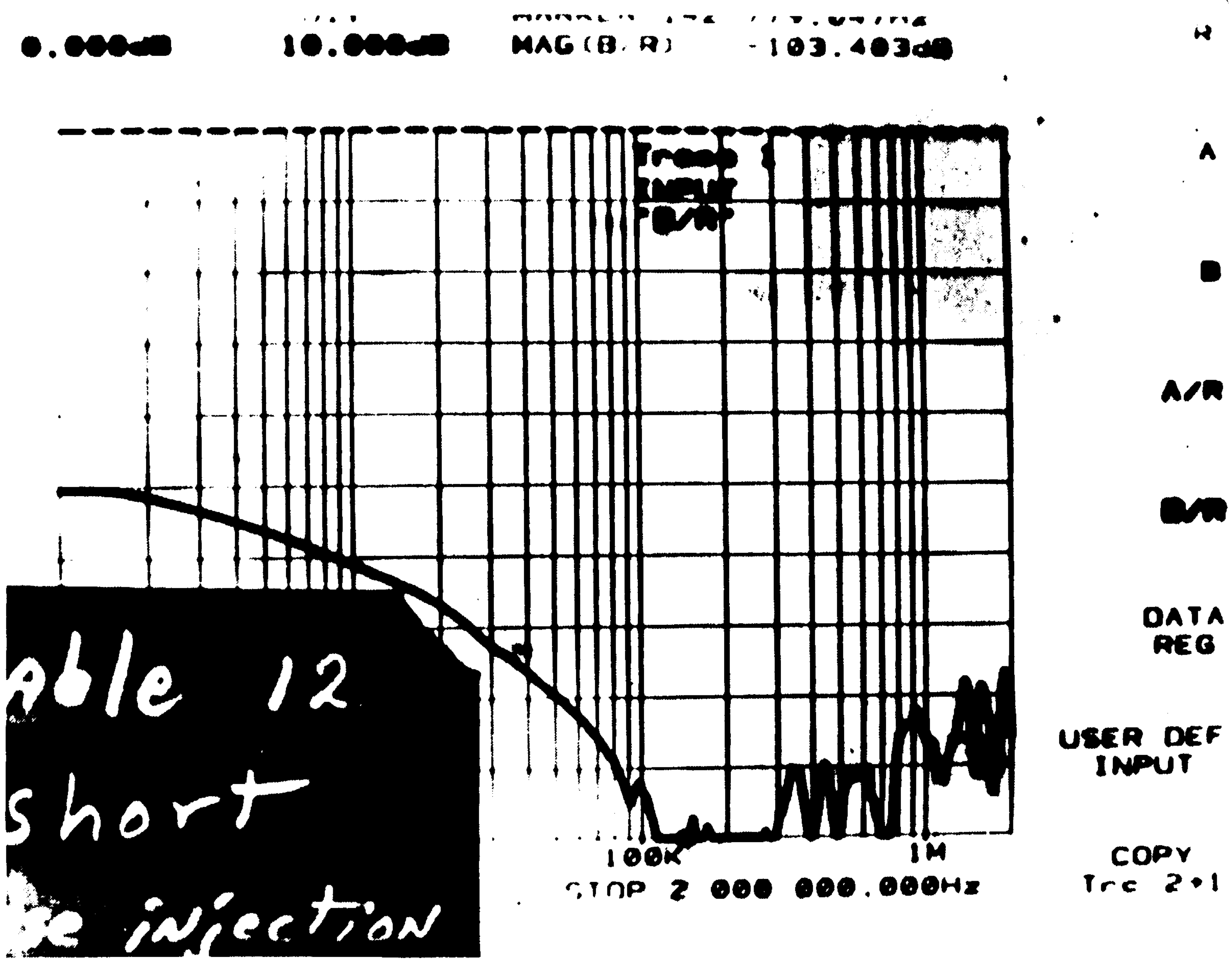
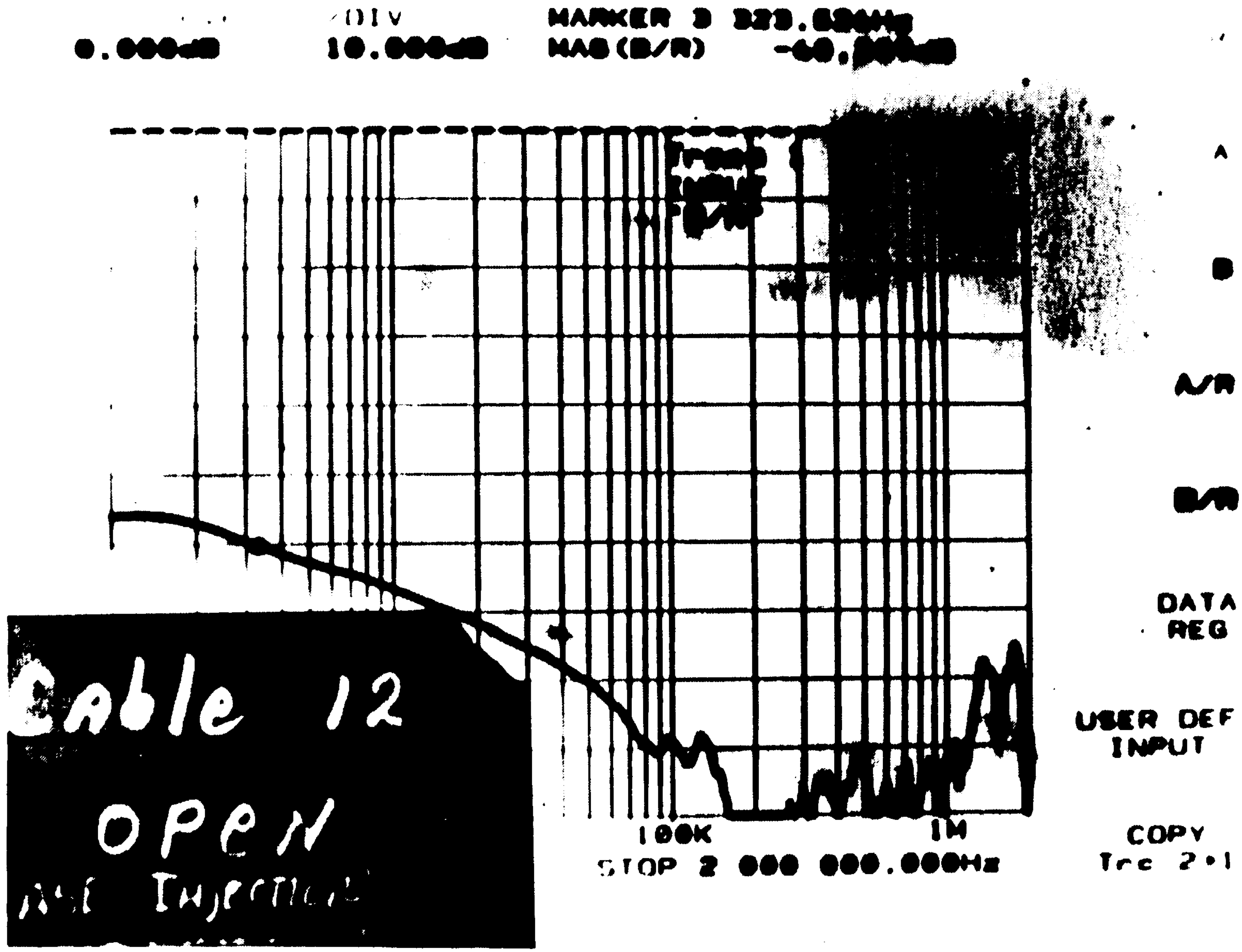
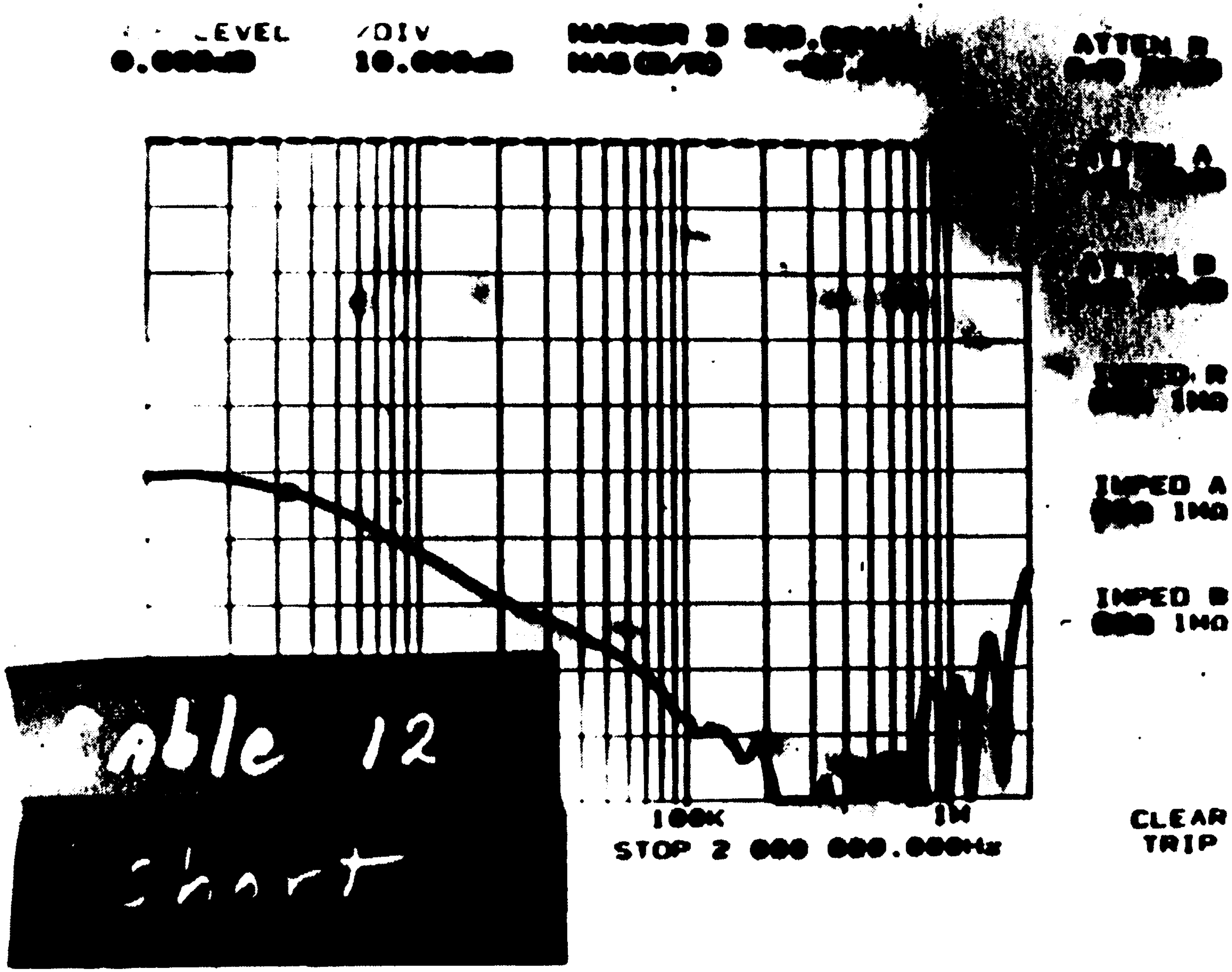


Swept Continuous Wave #35, Attach point: station 1701, Cable #12, Short circuit current, EMI shields closed (subtract 18 dB)



Swept Continuous Wave #36, Attach point: station 1701, Cable #12, Open circuit voltage, EMI shields closed (subtract 18 dB)



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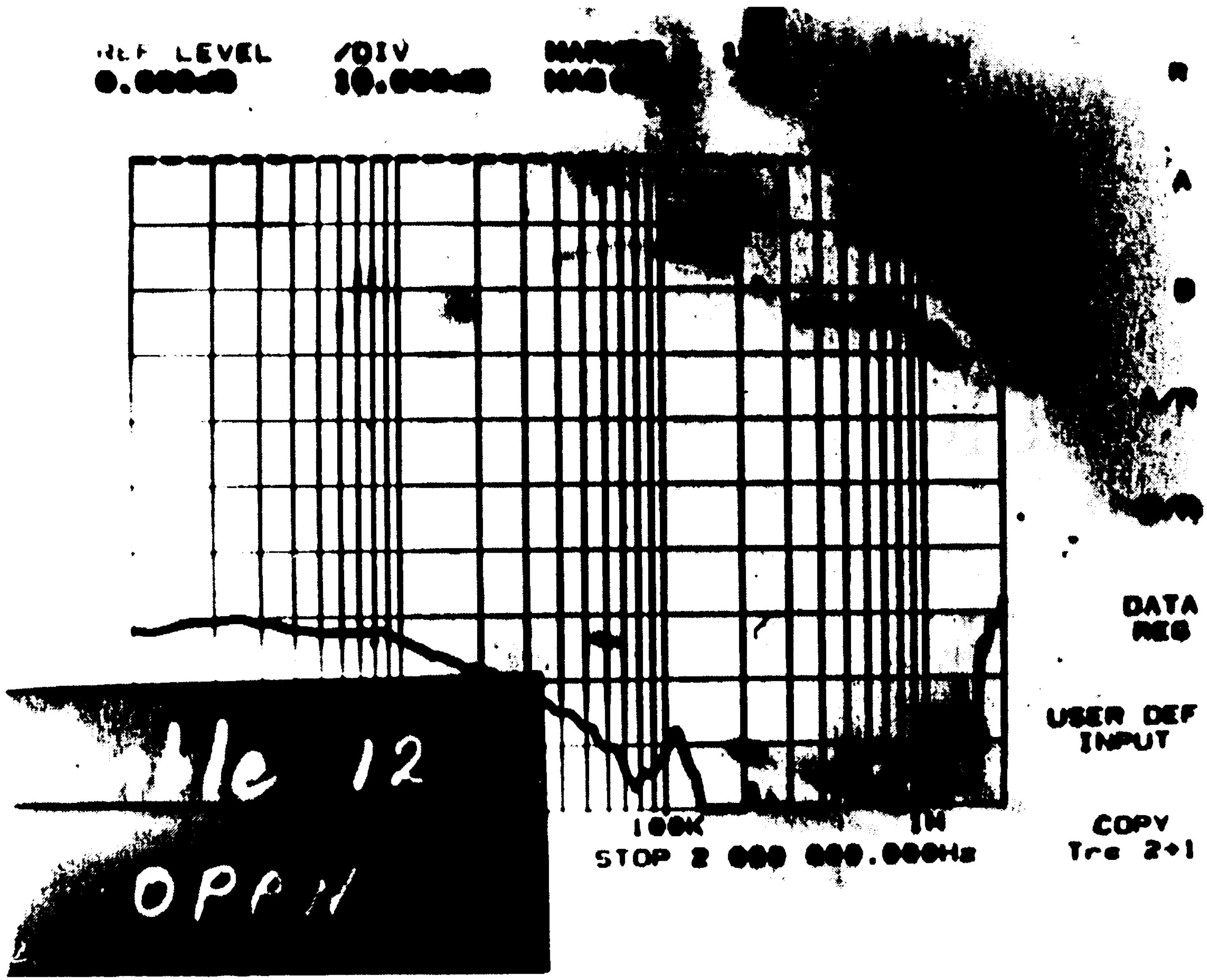

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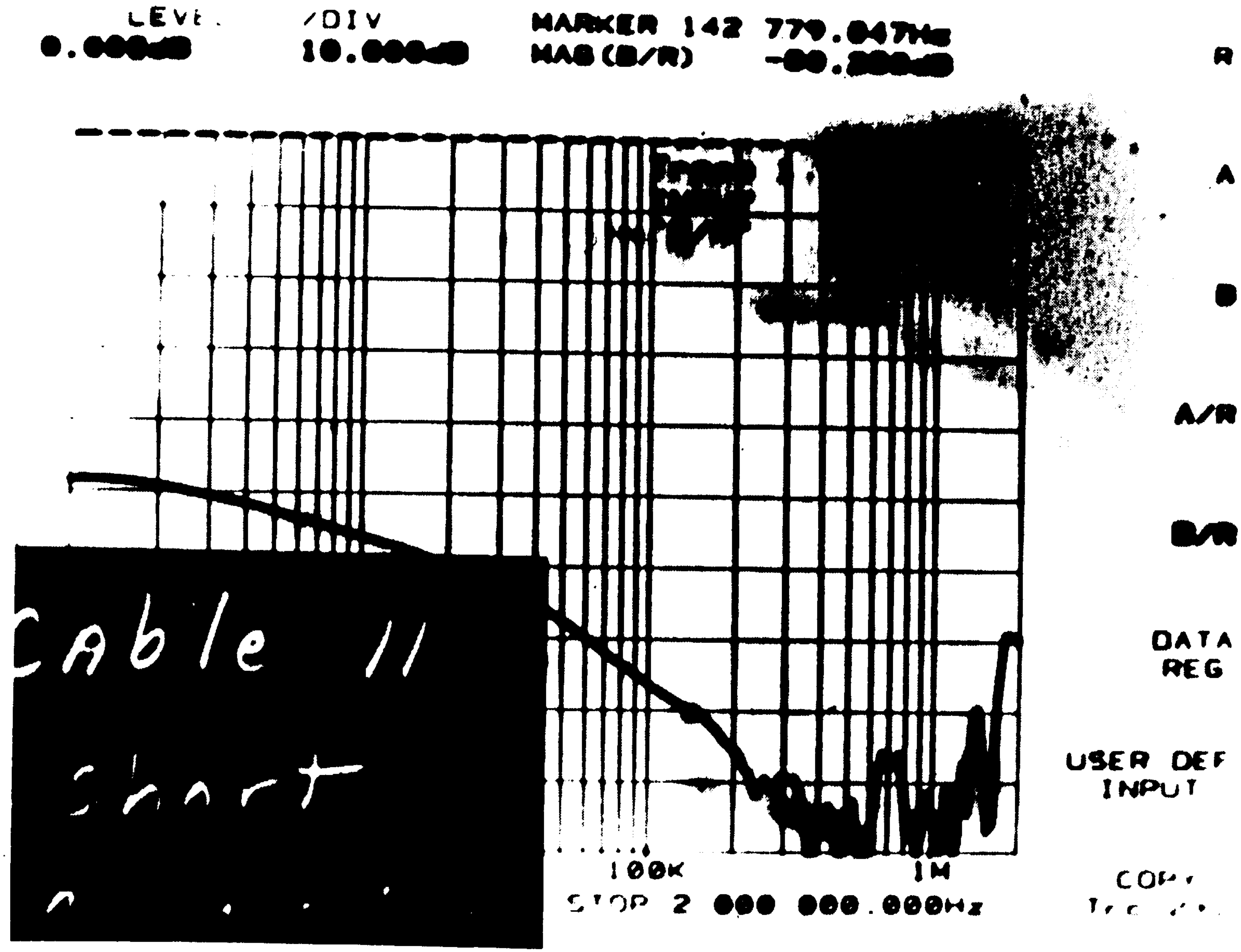

Swept Continuous Wave #41, Attach point: station 1829, Cable #11, Short circuit current, EMI shields closed (subtract 18 dB)

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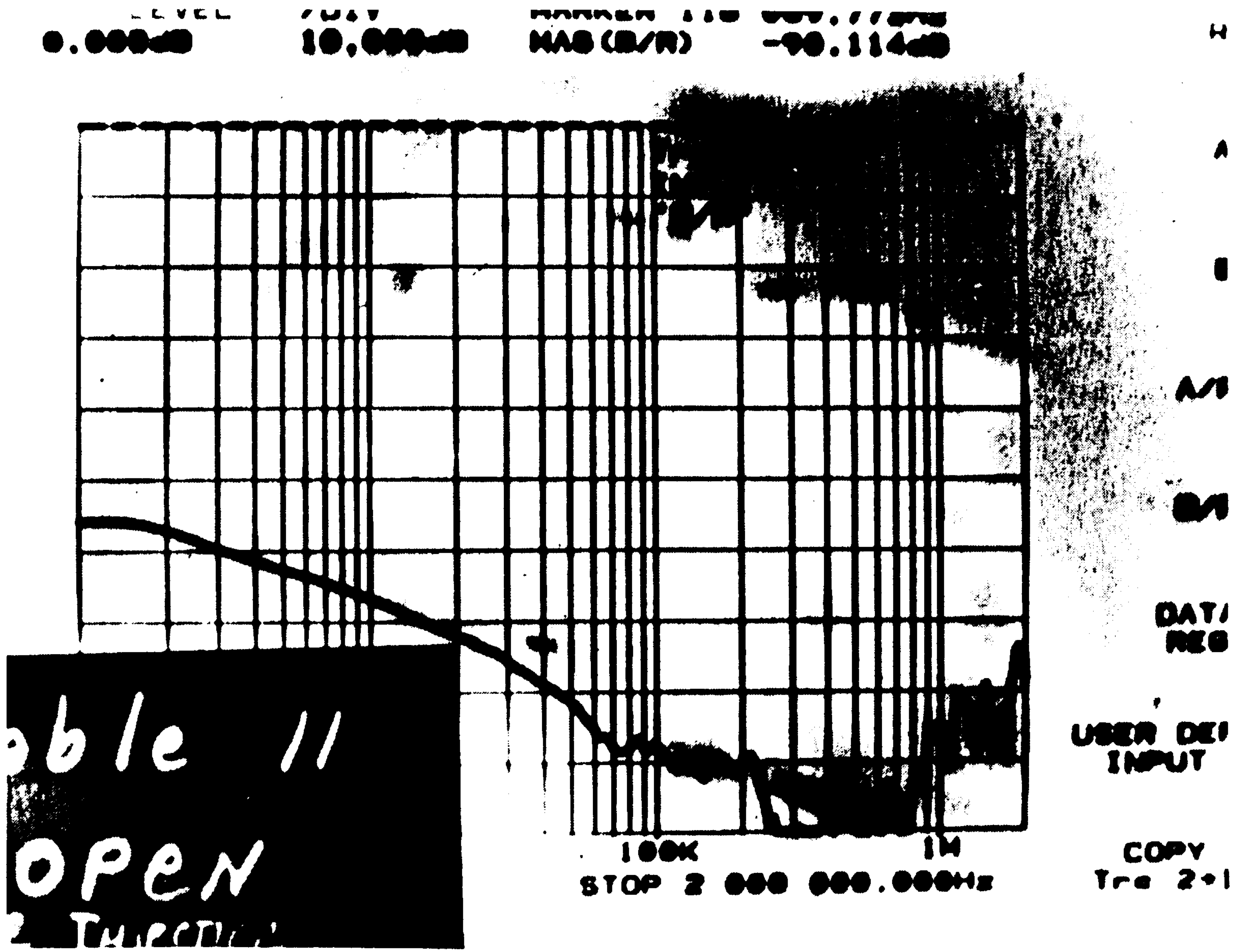

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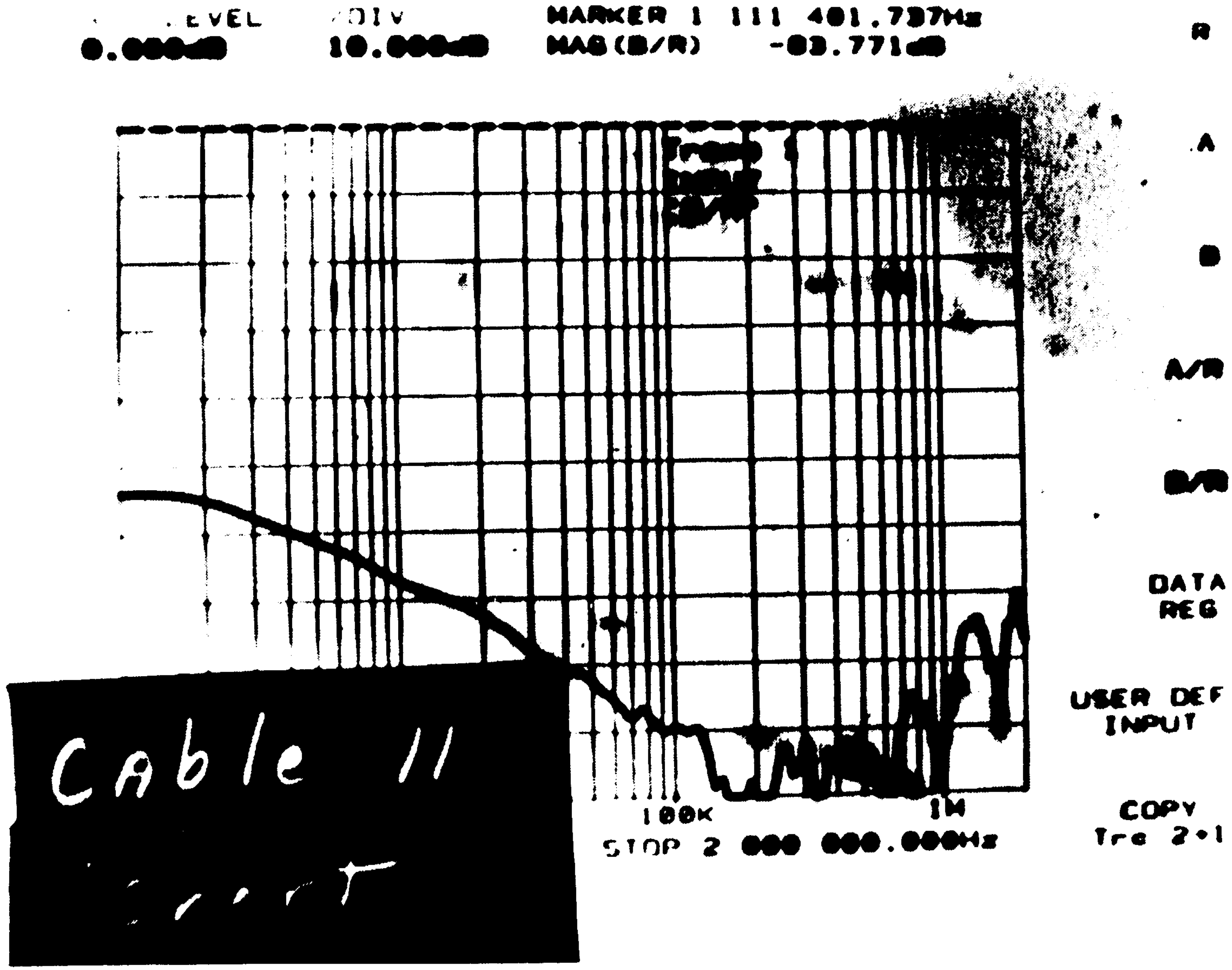

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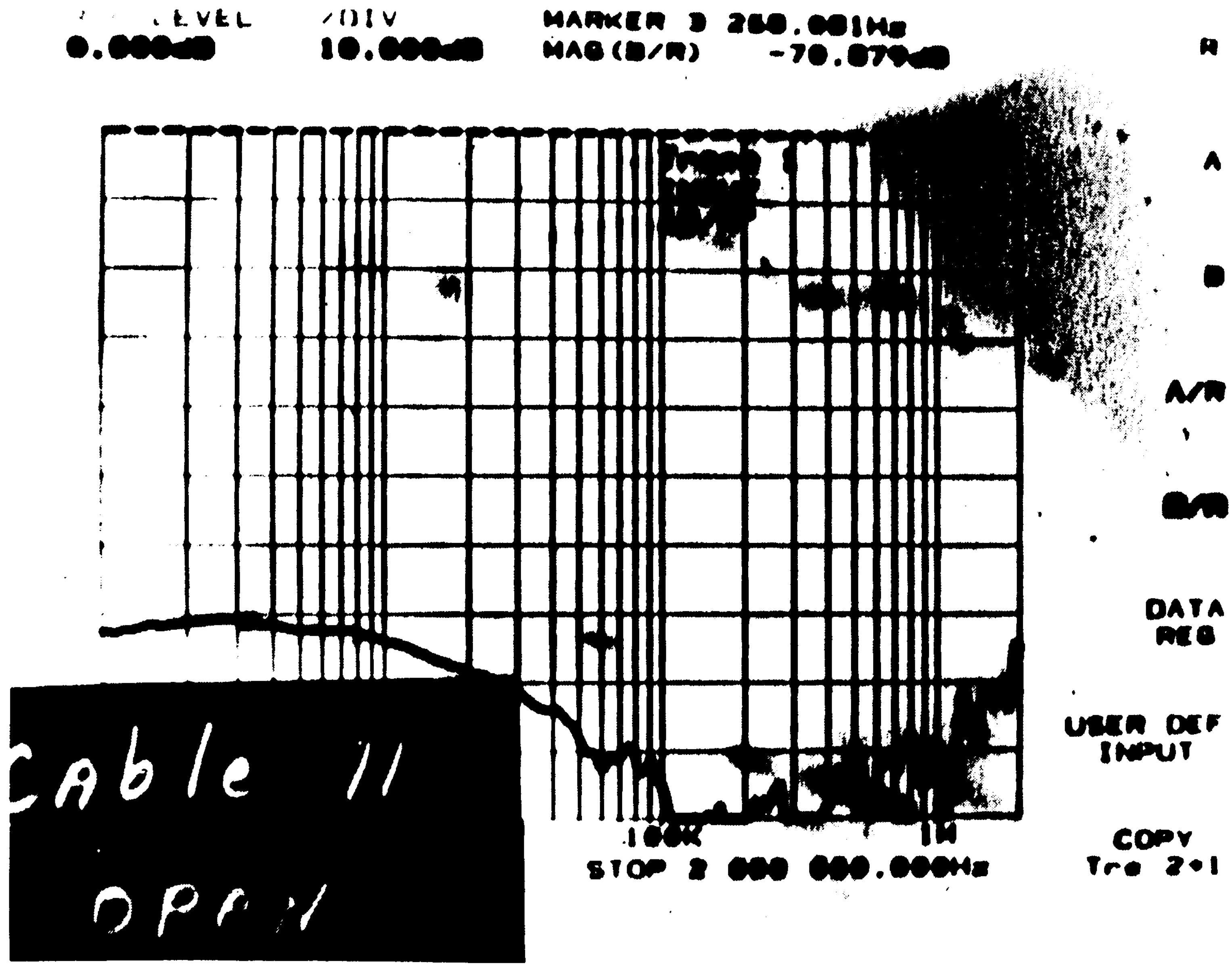

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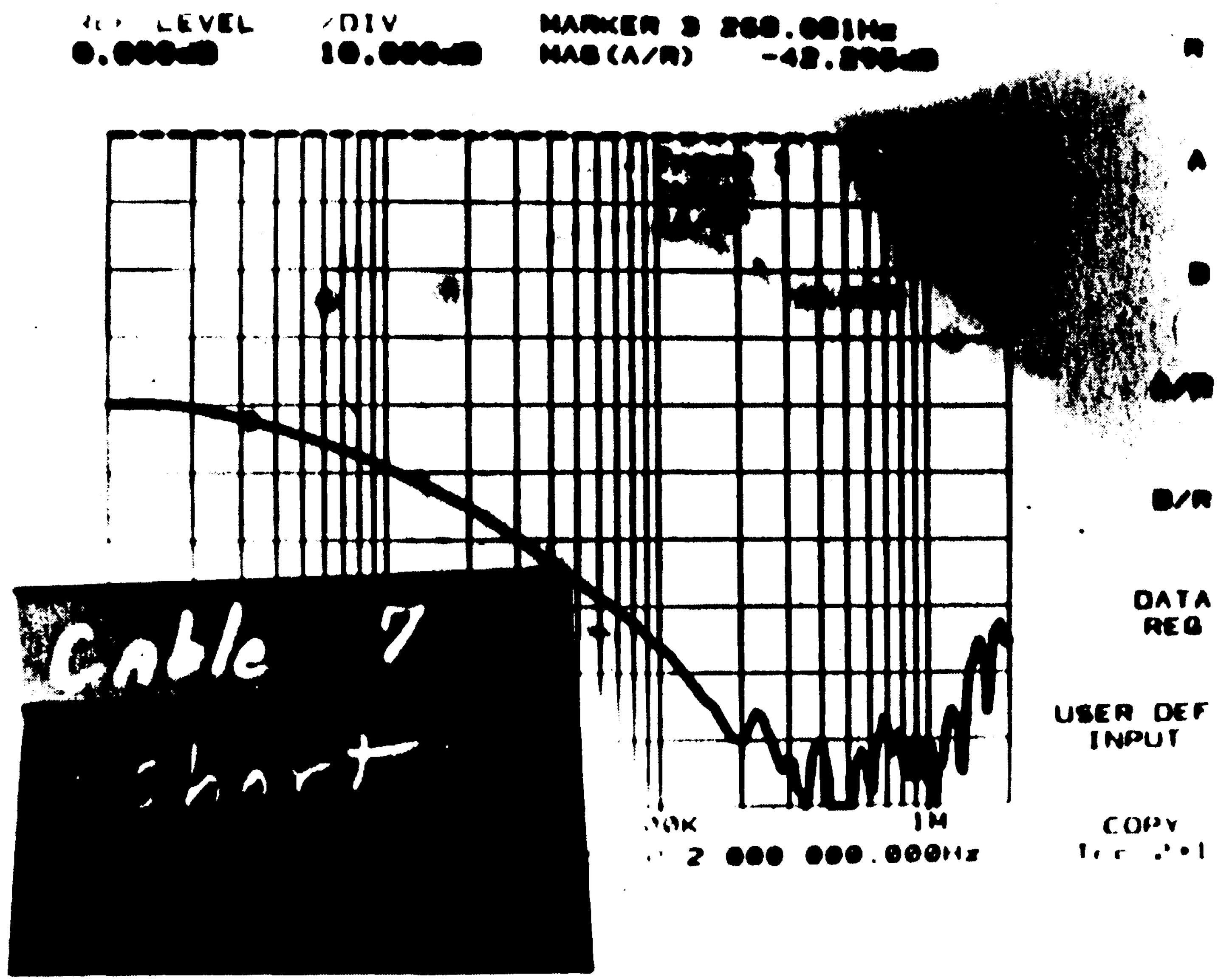

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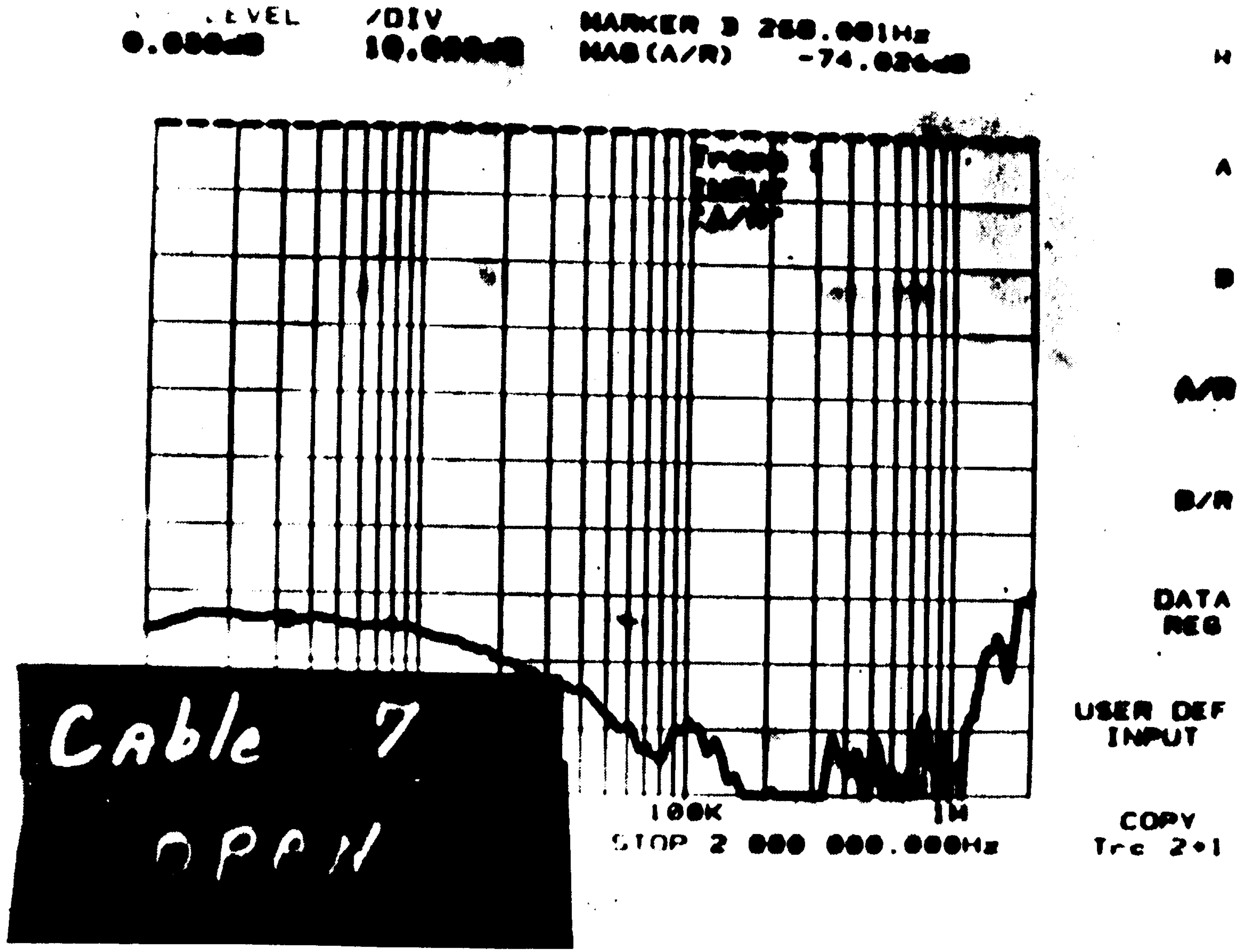
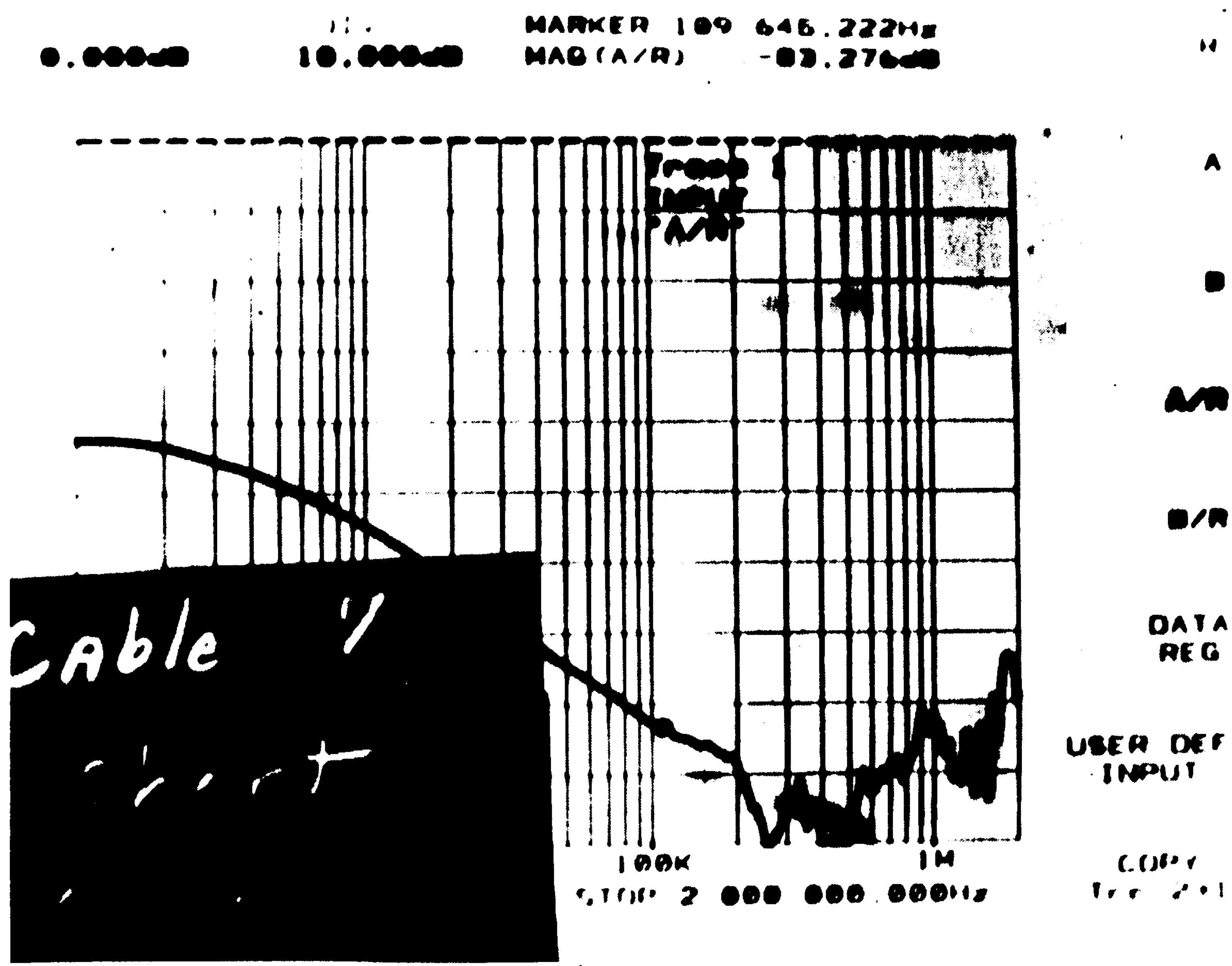


Swept Continuous Wave #46, Attach point #1, Cable #7, Open circuit voltage, EMI shields open (subtract 18 dB)



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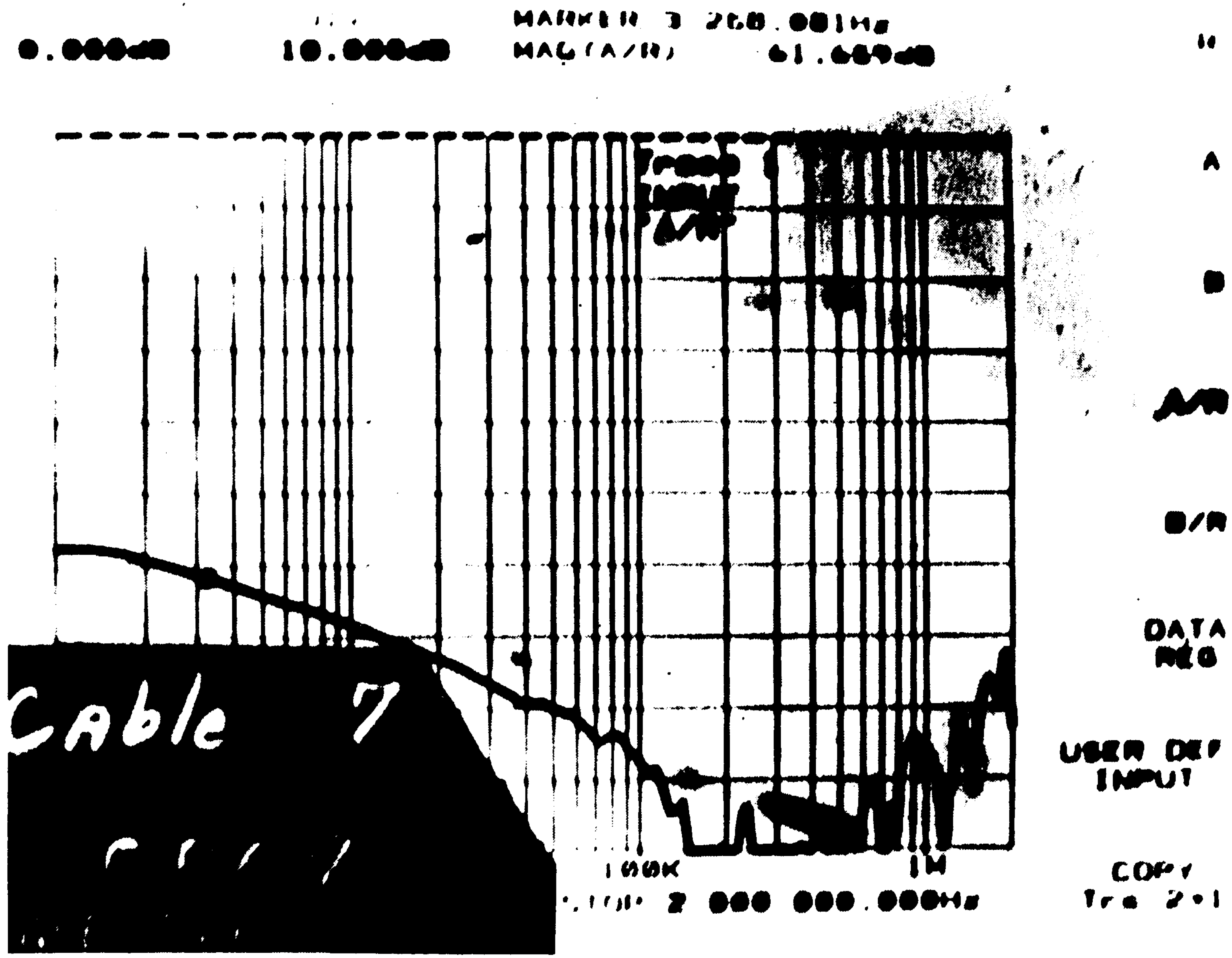

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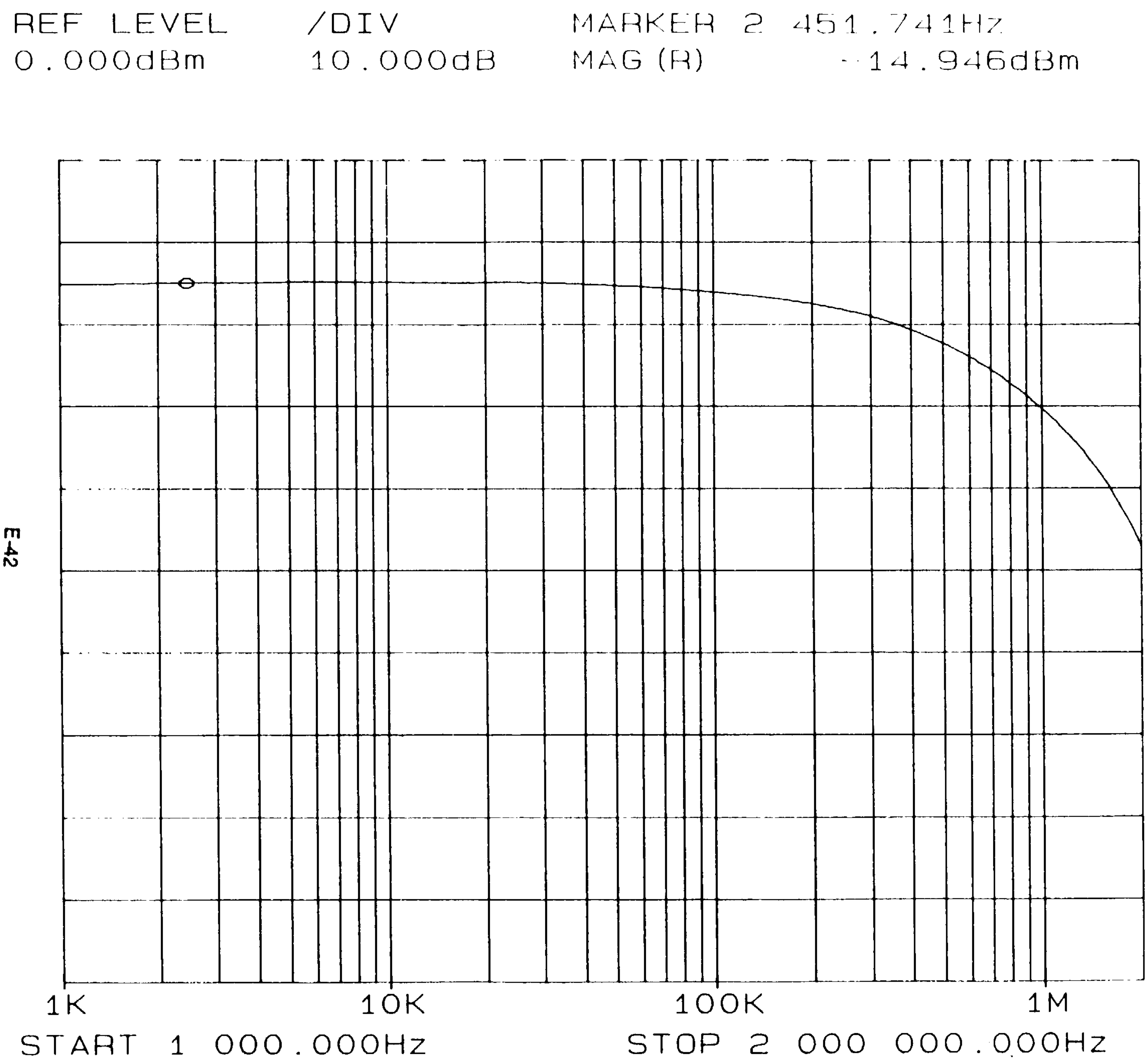
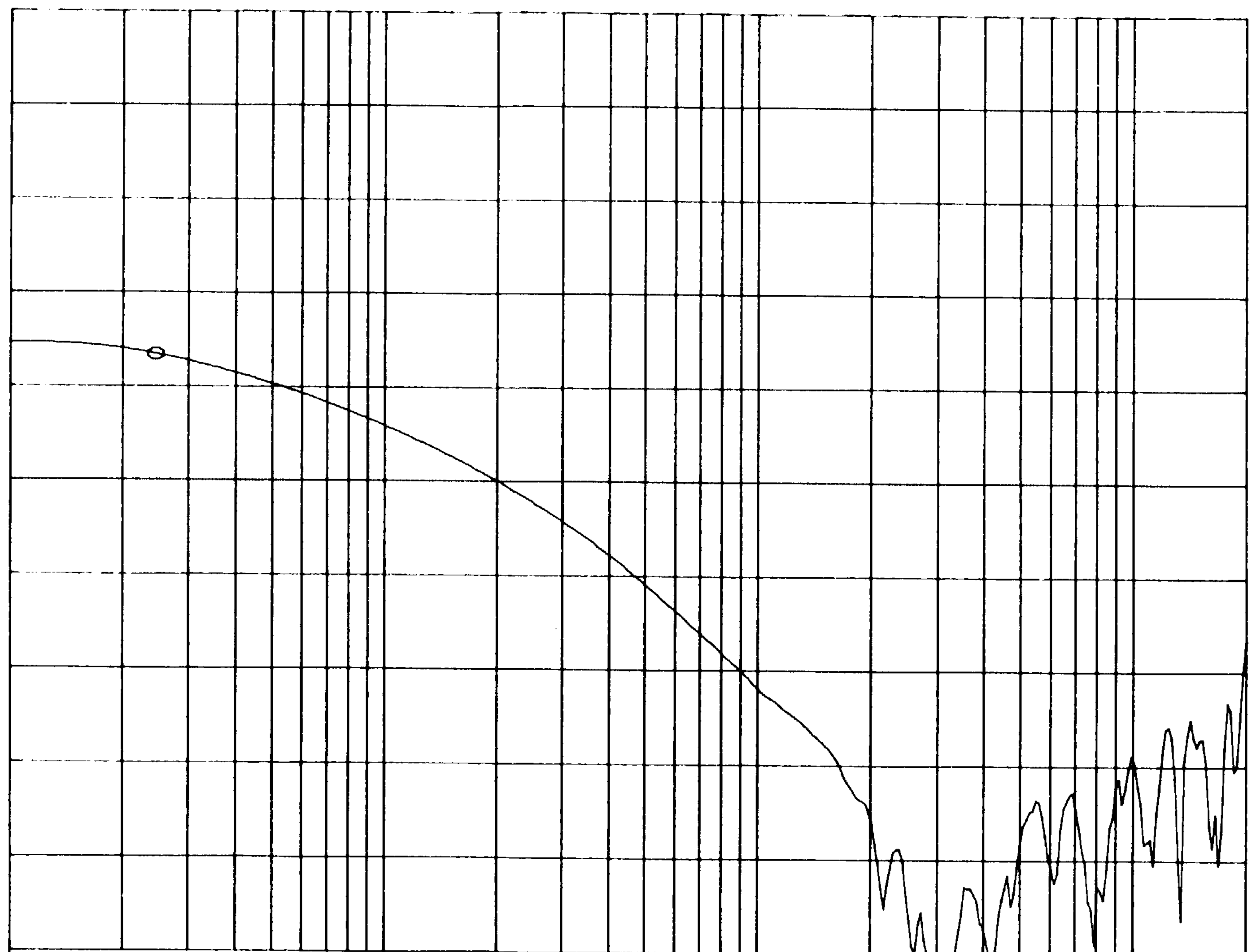


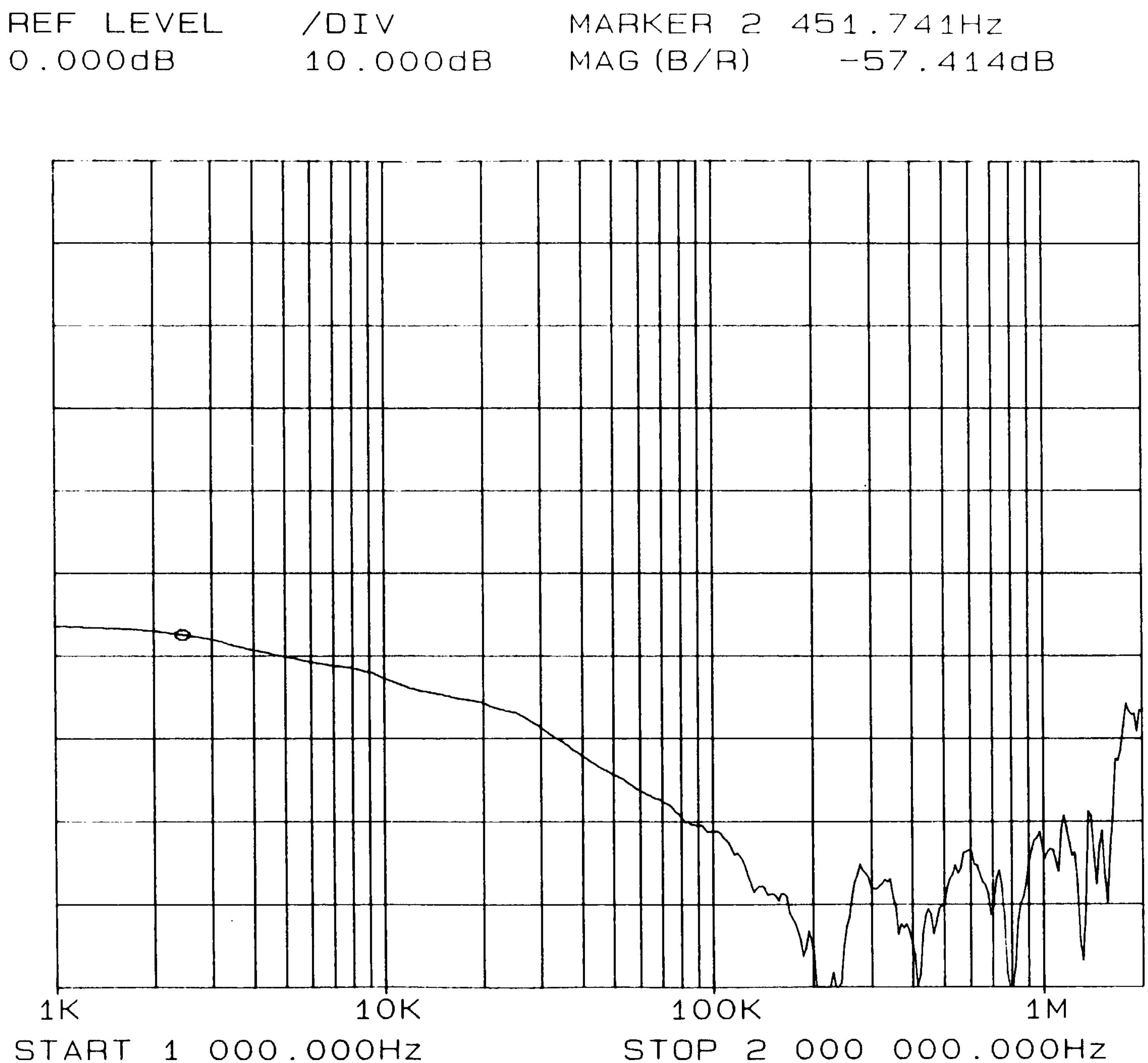
Swept Continuous Wave #55, Injection (add 18 dB)

REF LEVEL /DIV MARKER 2 451.741Hz
0.000dB 10.000dB MAG (A/R) -36.521dB



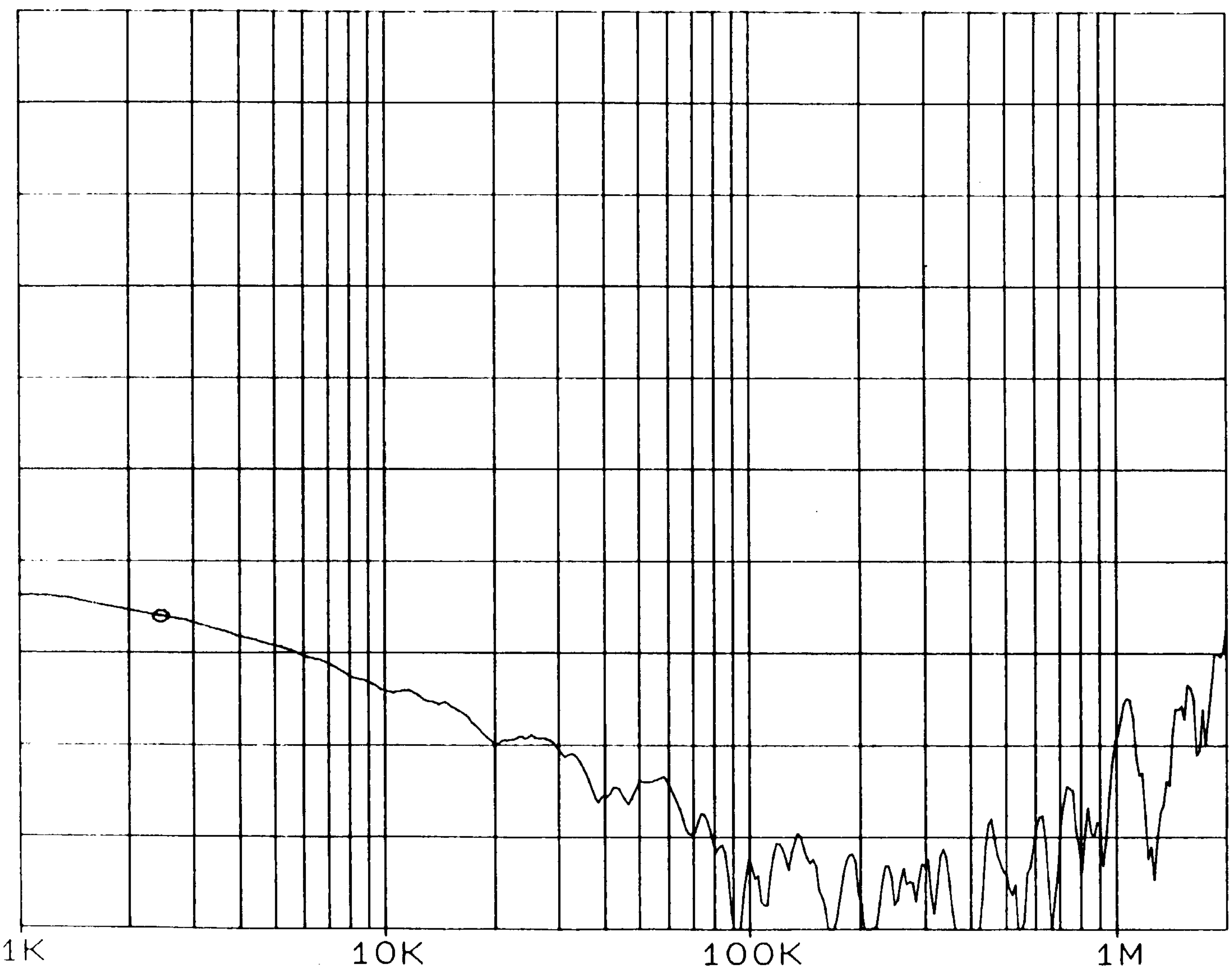
START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #56, Attach point #1, Cable #7, Short circuit current, EMI shields open (subtract 18 dB)



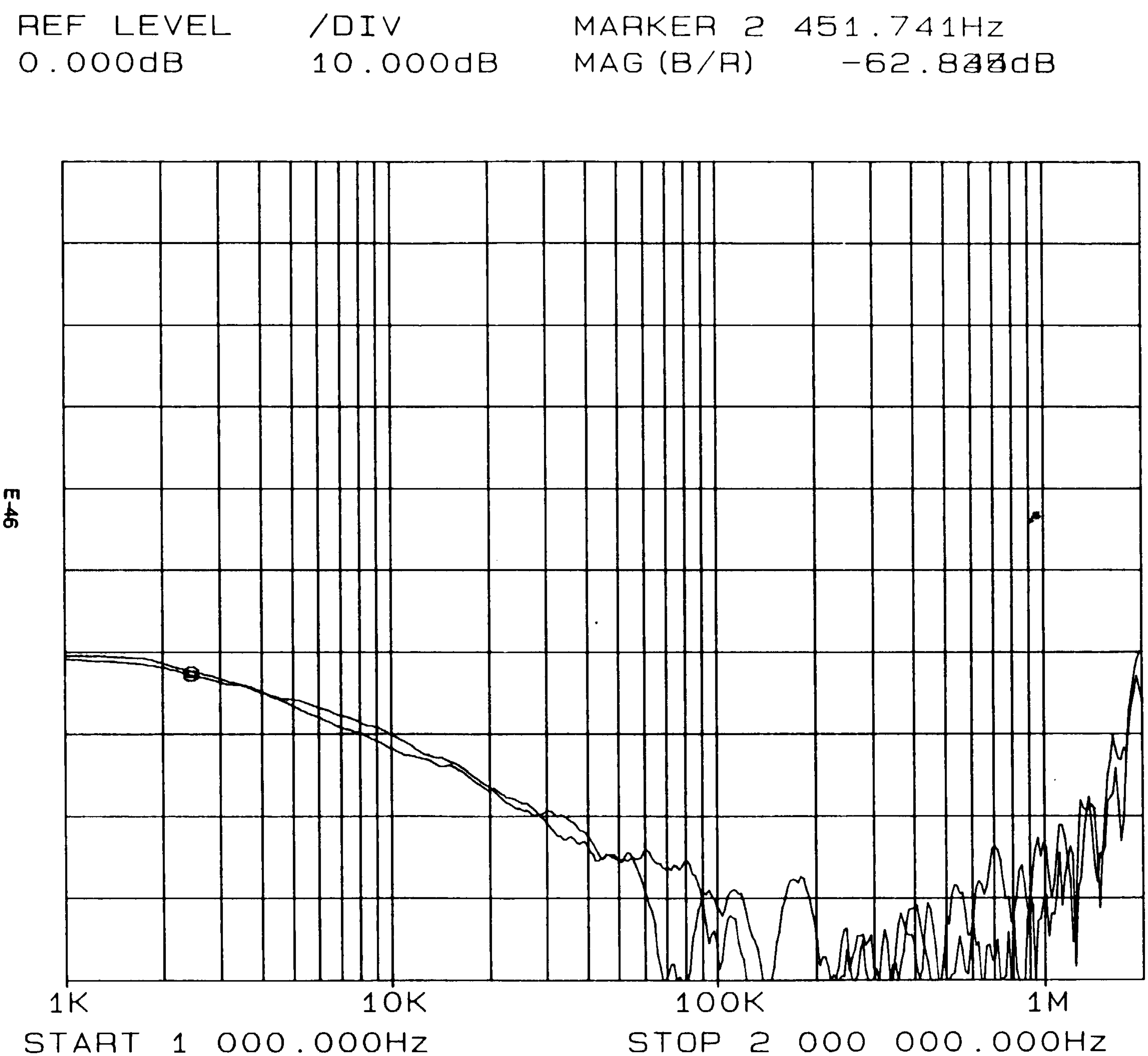
Swept Continuous Wave #57, Attach point #1, Cable #11, Short circuit current, EMI shields open (subtract 18 dB)

REF LEVEL /DIV MARKER 2 451.741Hz
0.000dB 10.000dB MAG (A/R) -65.942dB



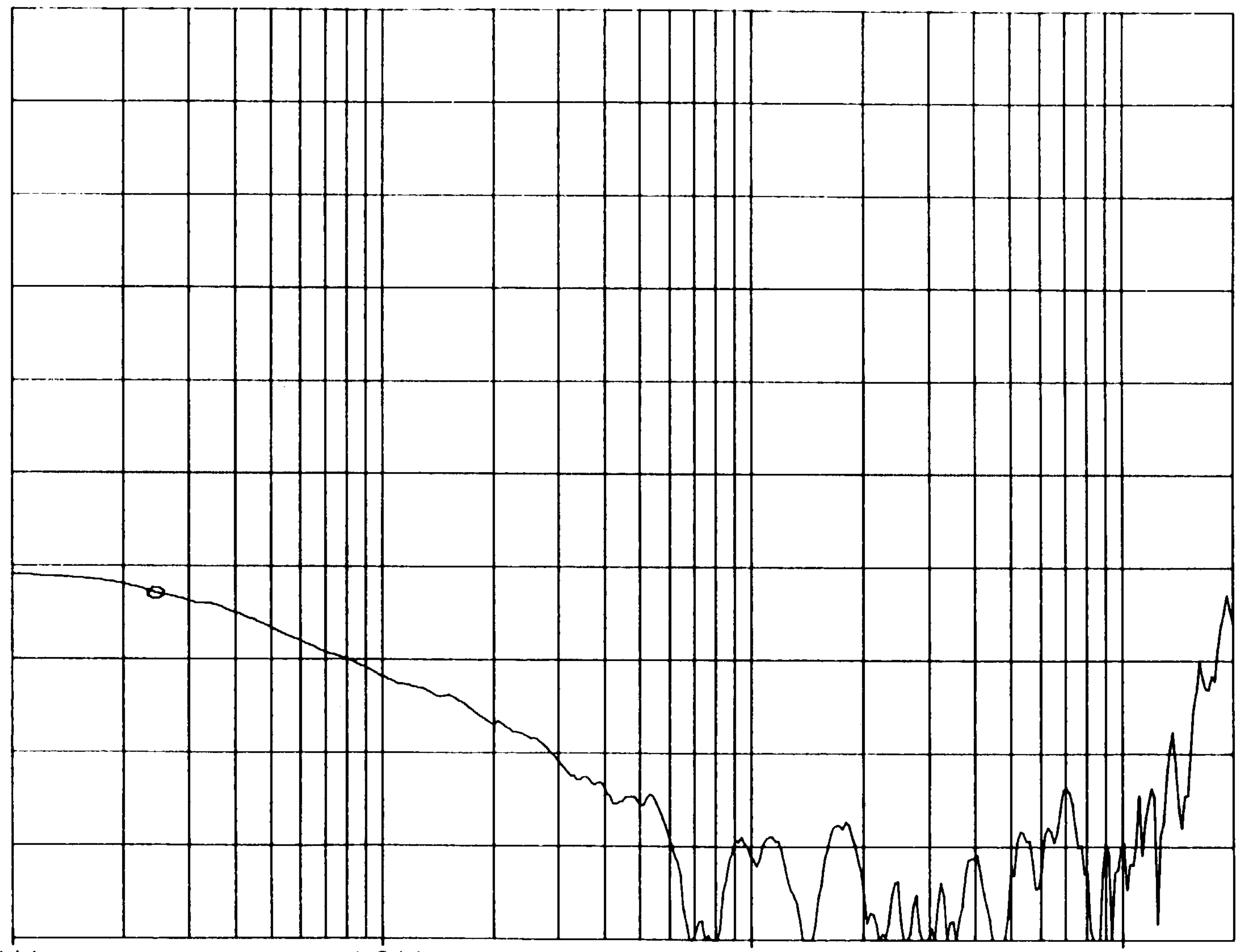
START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #58, Attach point #1, Cable #7, Open circuit voltage, EMI shields open (subtract 18 dB)



Swept Continuous Wave #59, Attach point #1, Cable #11, Open circuit voltage, EMI shields open (subtract 18 dB)

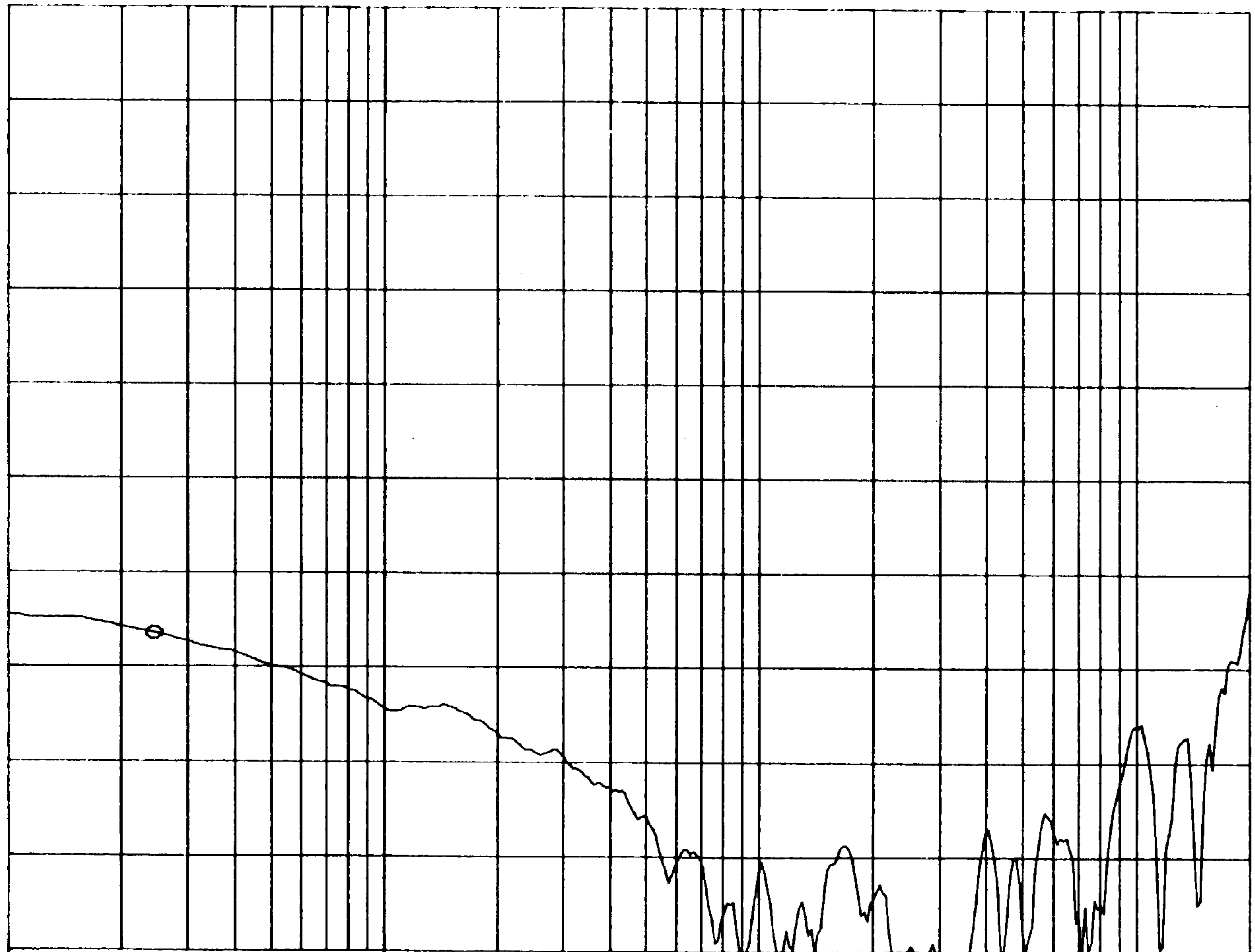
REF LEVEL /DIV MARKER 2 451.741Hz
0.000dB 10.000dB MAG (B/R) -62.834dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #60, Attach point: station 1701, Cable #11, Open circuit voltage, EMI shields open (subtract 18 dB)

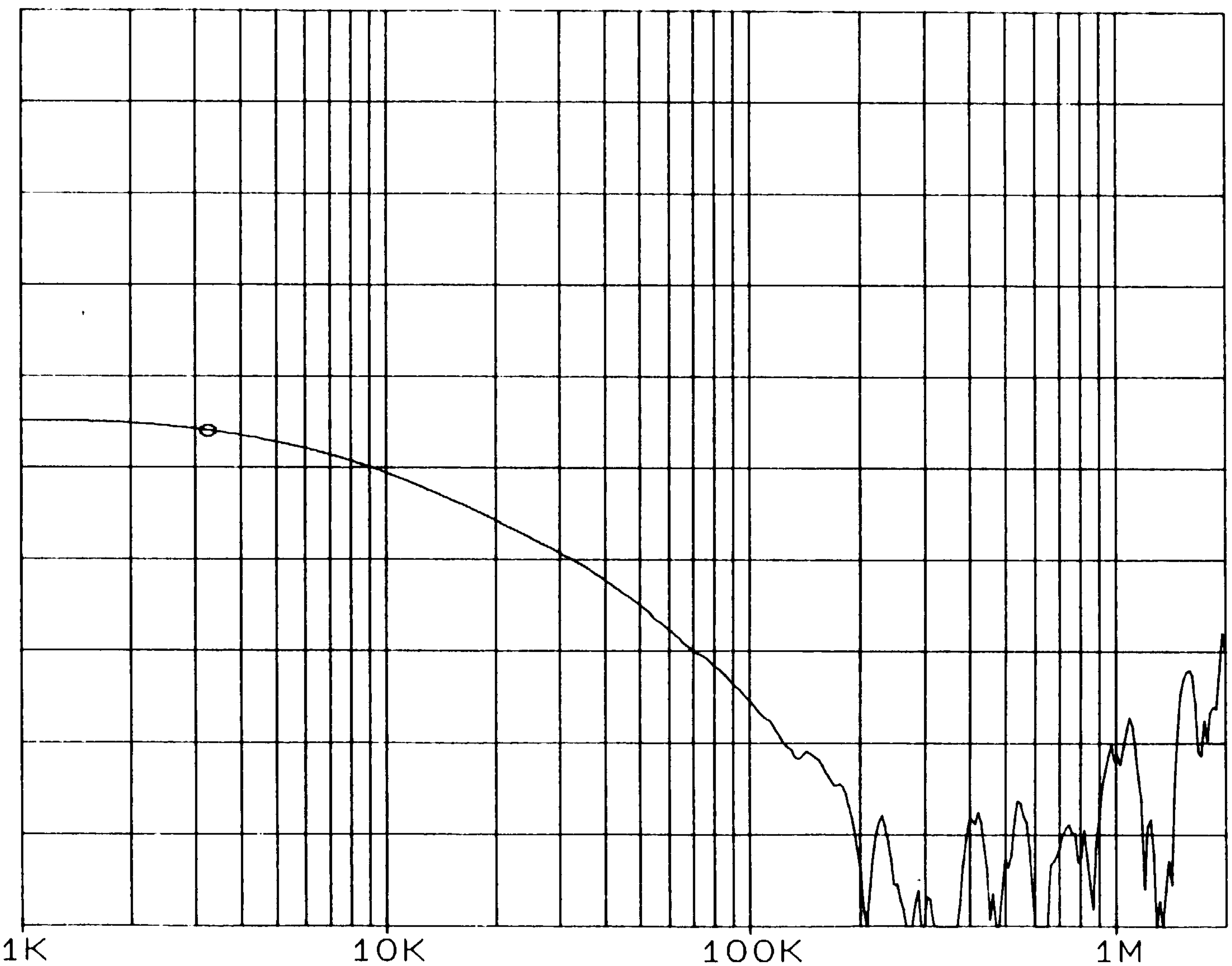
REF LEVEL /DIV MARKER 2 451.741Hz
0.000dB 10.000dB MAG (A/R) -66.348dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #61, Attach point: station 1701, Cable #7, Open circuit voltage, EMI shields open (subtract 18 dB)

REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (A/R) -45.895dB

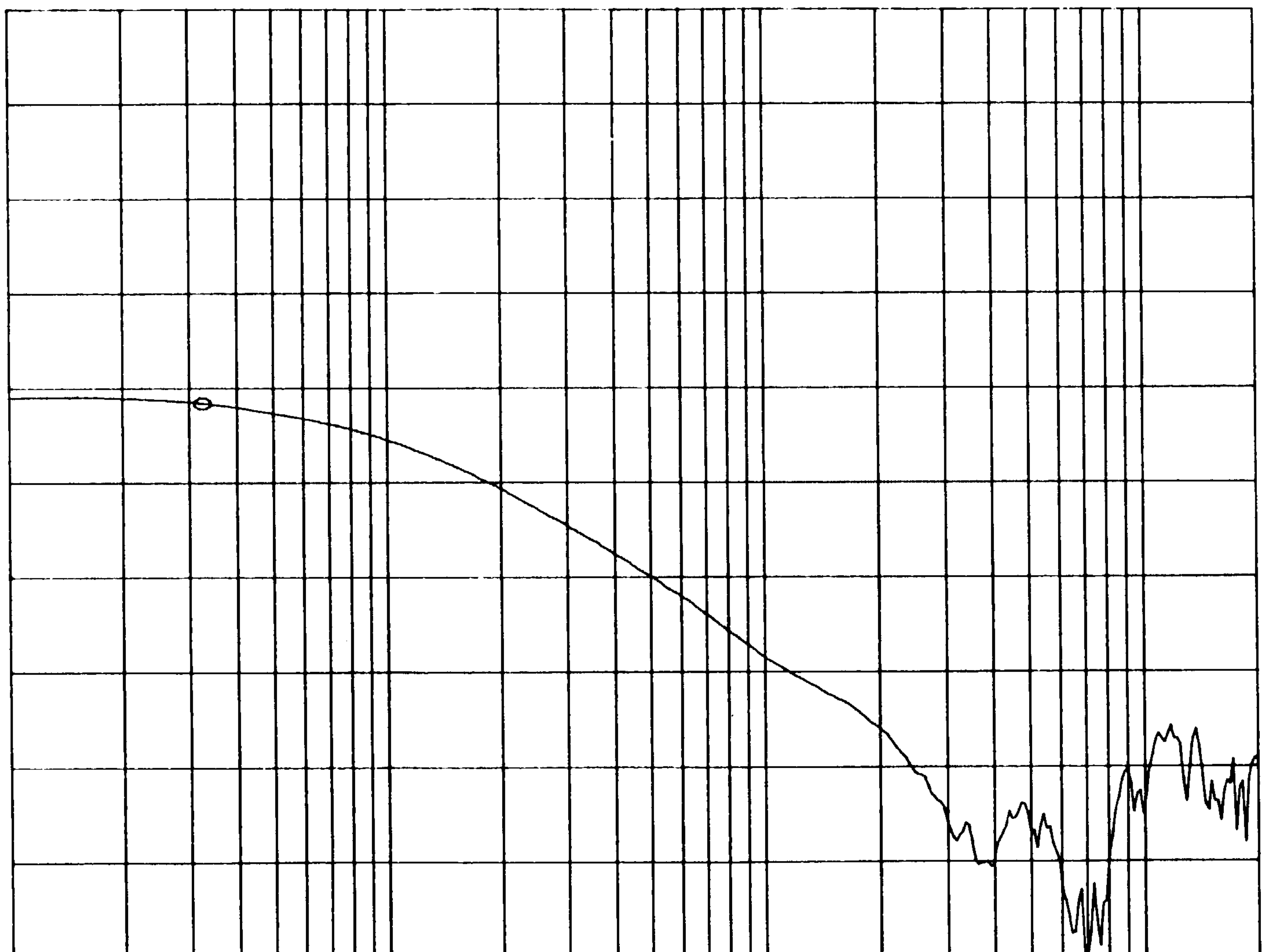


START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #62, Attach point: station 1701, Cable #7, Short circuit current, EMI shields open (subtract 18 dB)

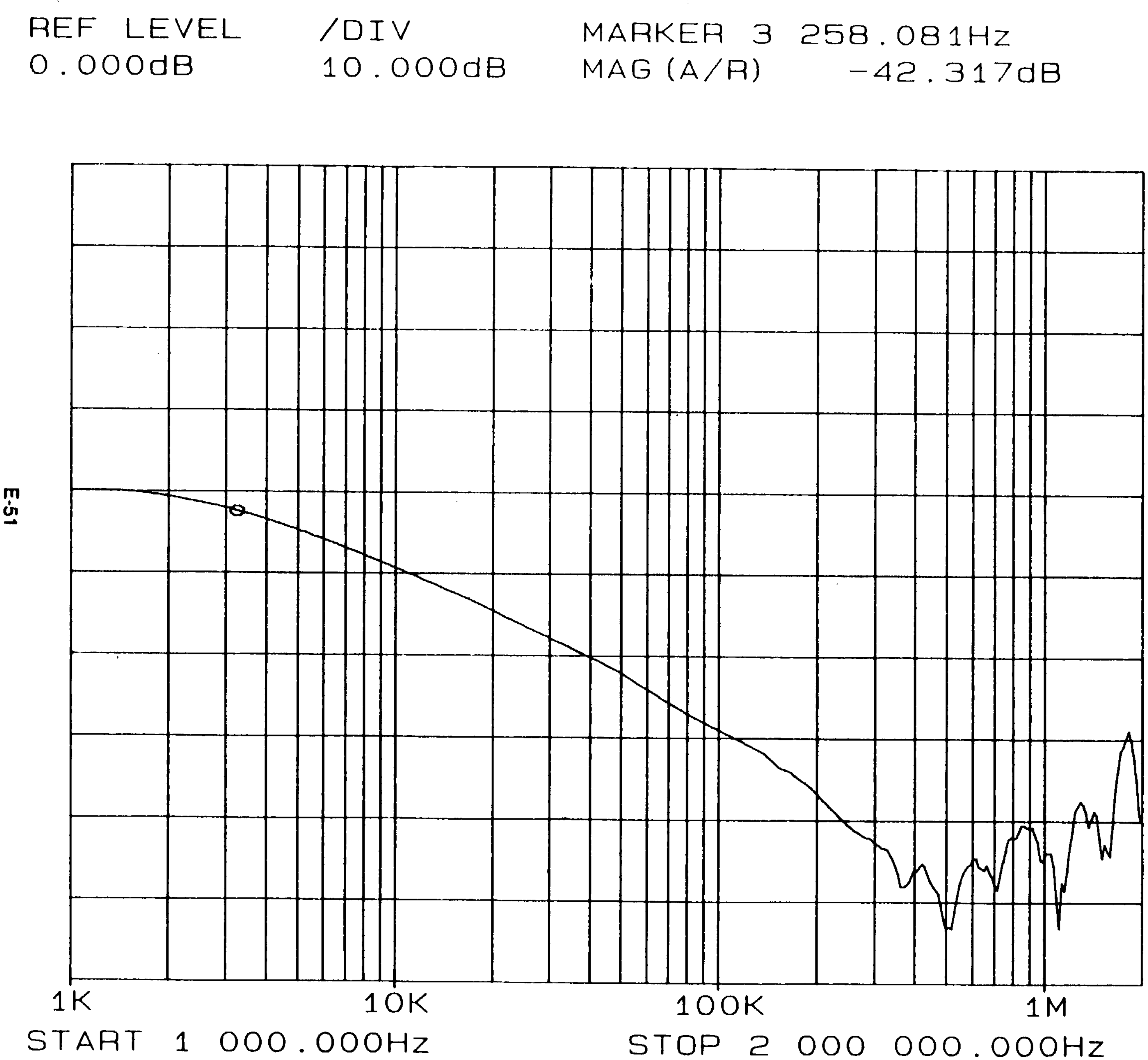
CW-63
1701 - 11SC (EMI-O

REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -41.557dB

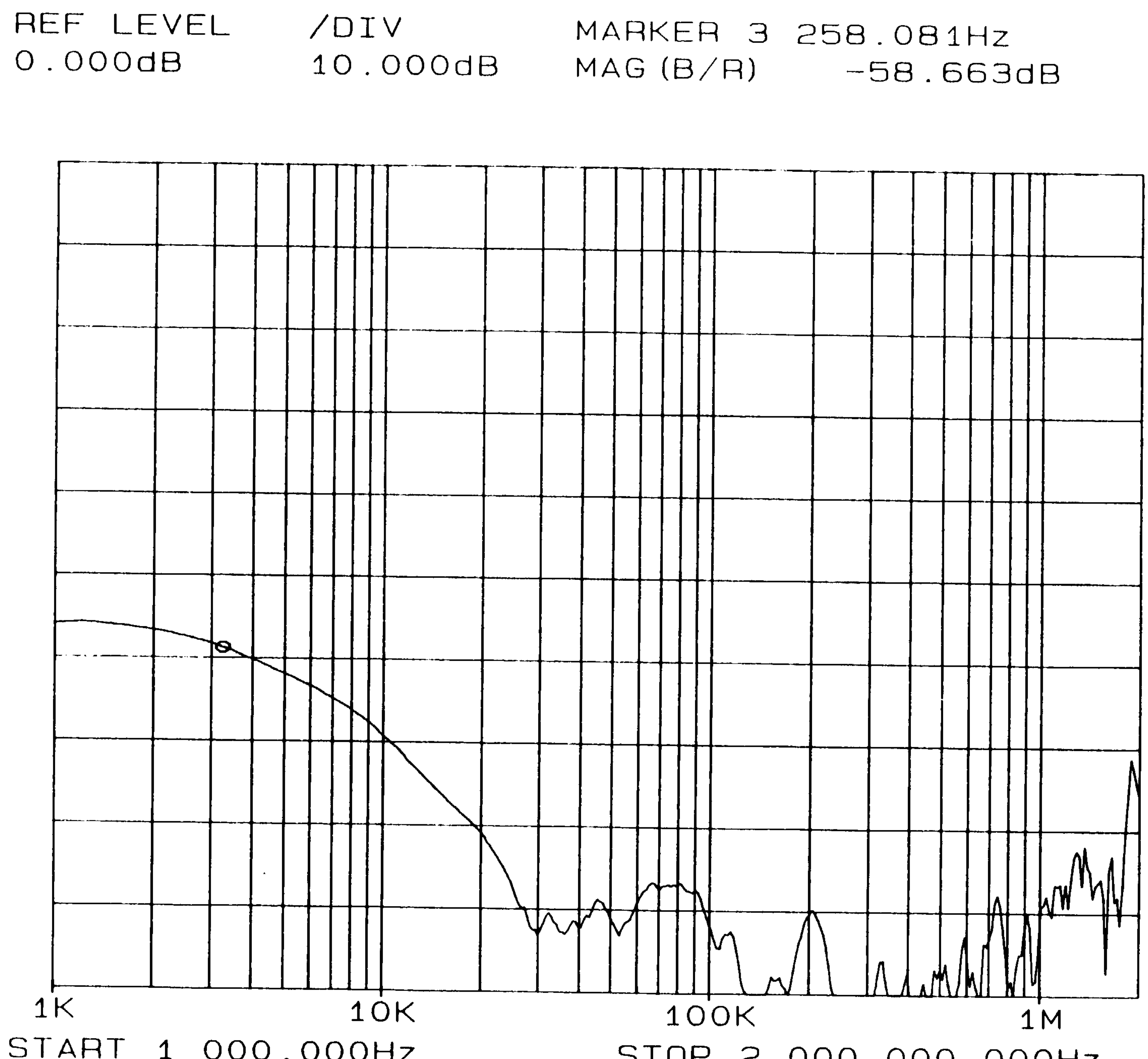


START 1 000.000Hz STOP 2 000 000.000Hz

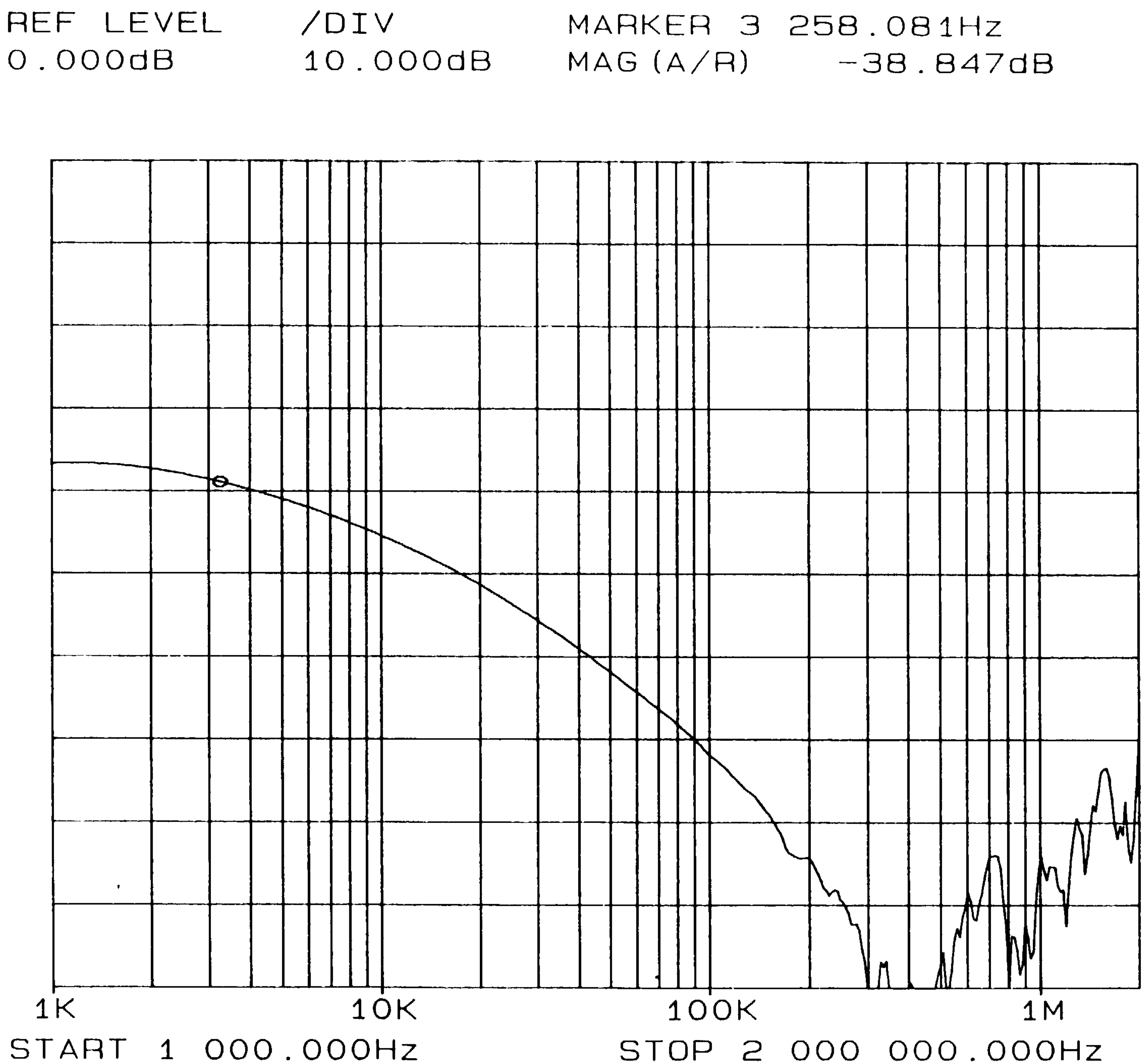
Swept Continuous Wave #63, Attach point: station 1701, Cable #11, Short circuit current, EMI shields open (subtract 18 dB)



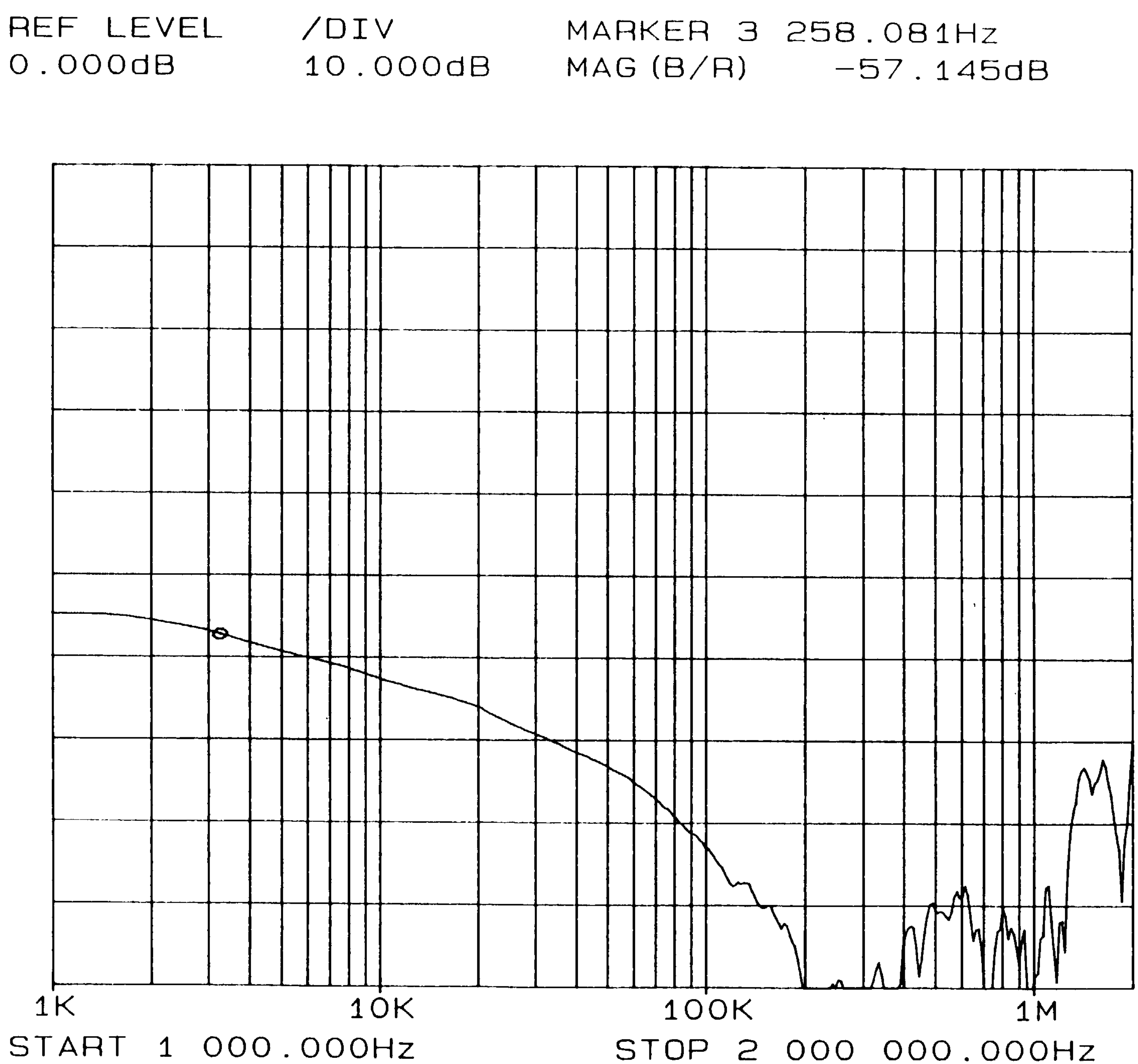
Swept Continuous Wave #64, Attach point #1, Cable #6, Short circuit current, EMI shields closed (subtract 18 dB)



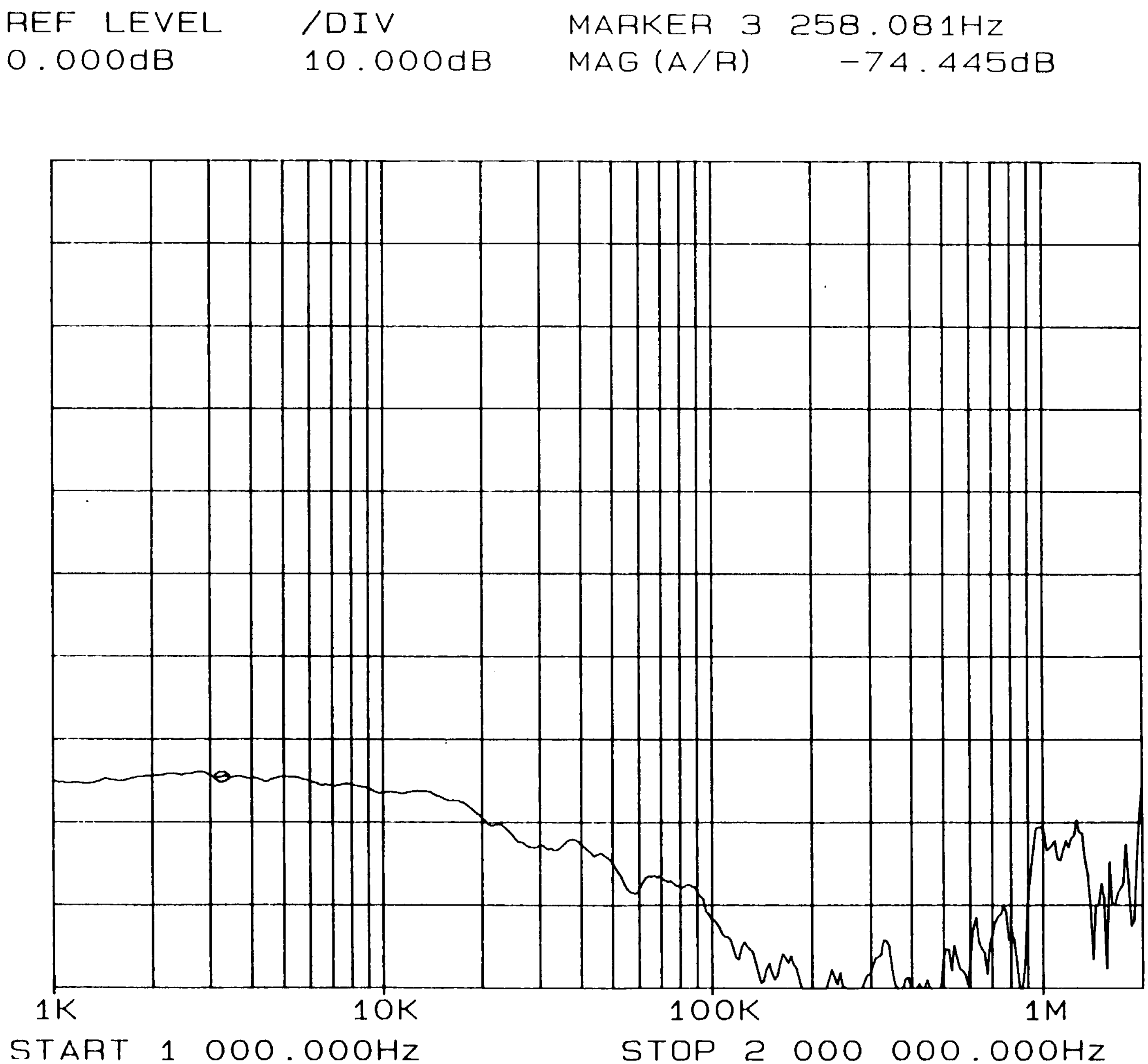
Swept Continuous Wave #65, Attach point #1, Cable #12, Short circuit current, EMI shields closed (subtract 18 dB)



Swept Continuous Wave #66, Attach point #1, Cable #7, Short circuit current, EMI shields closed (subtract 18 dB)

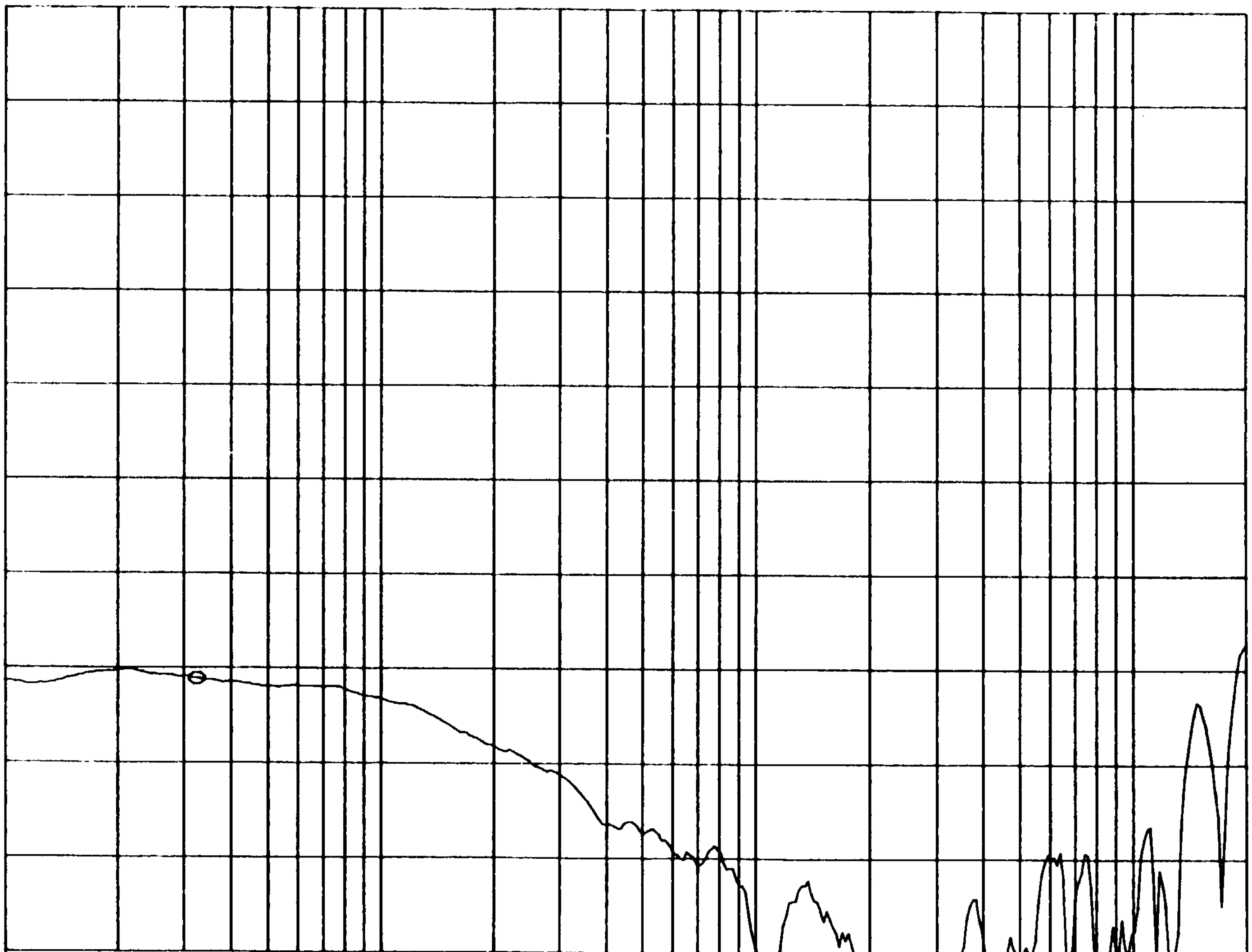


Swept Continuous Wave #67, Attach point #1, Cable #11, Short circuit current, EMI shields closed (subtract 18 dB)

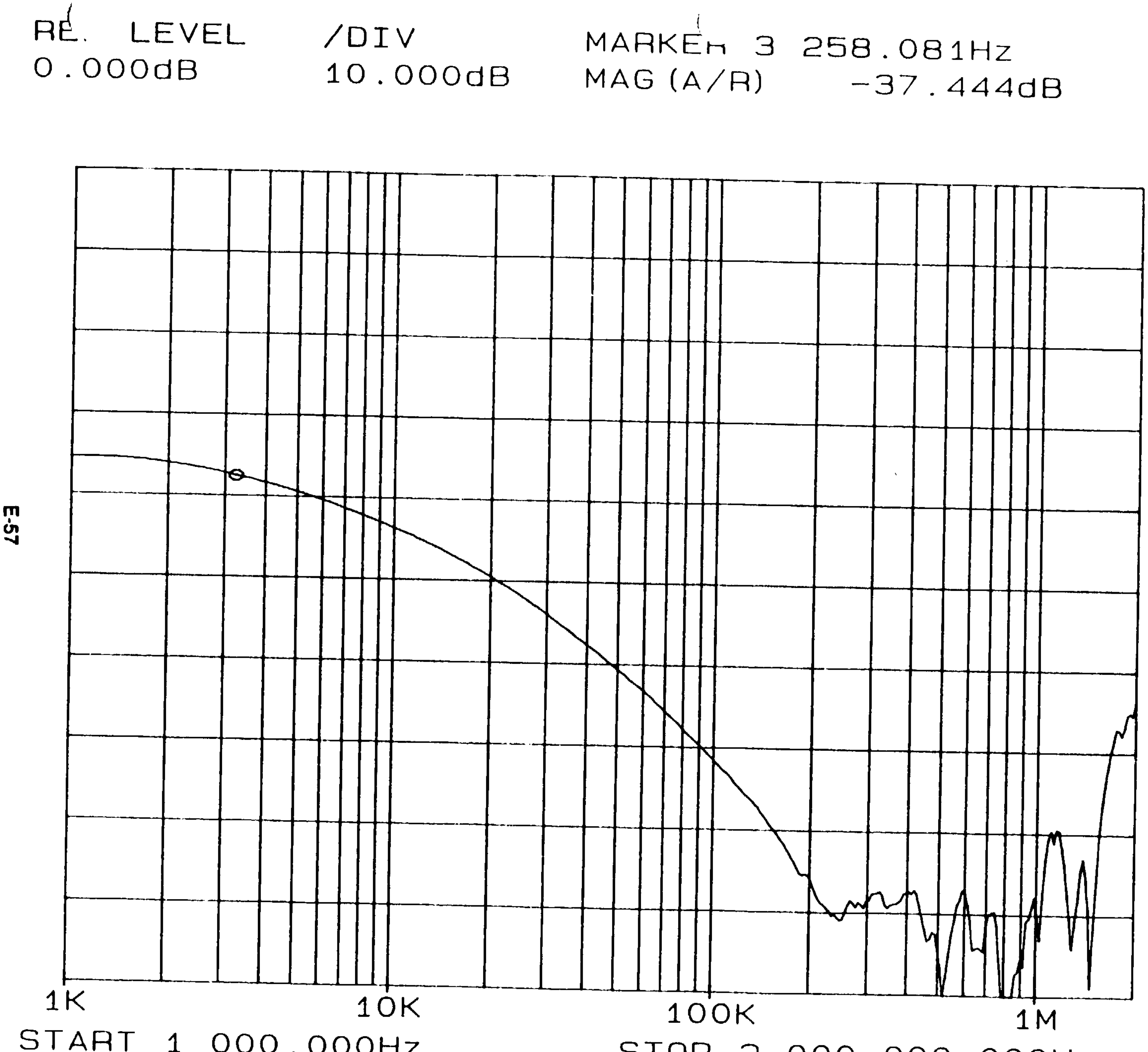


Swept Continuous Wave #68, Attach point #1, Cable #7, Open circuit voltage, EMI shields closed (subtract 18 dB)

REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -71.055dB

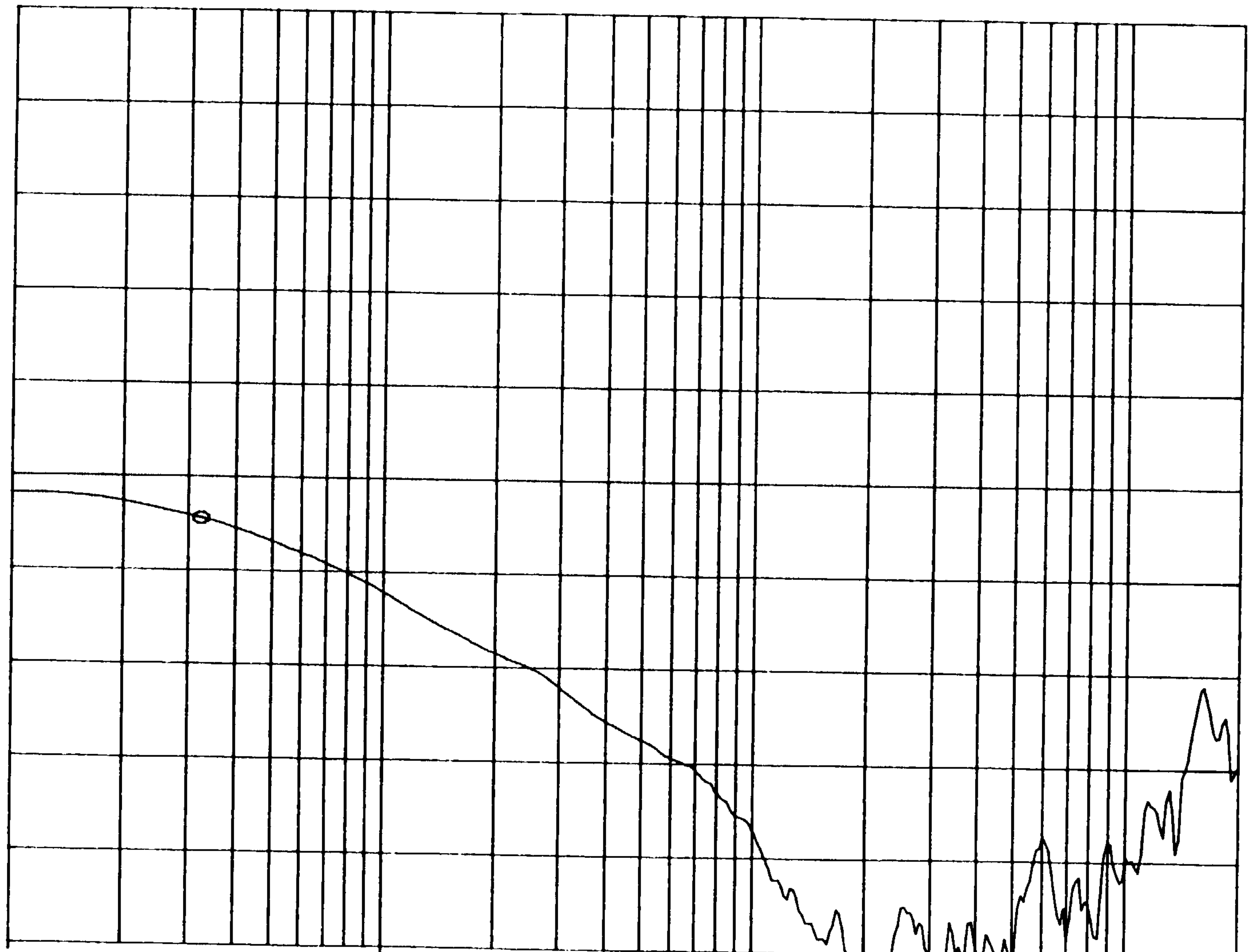


START 1 000.000Hz STOP 2 000 000.000Hz
Swept Continuous Wave #69, Attach point #1, Cable #11, Open circuit voltage, EMI shields closed (subtract 18 dB)



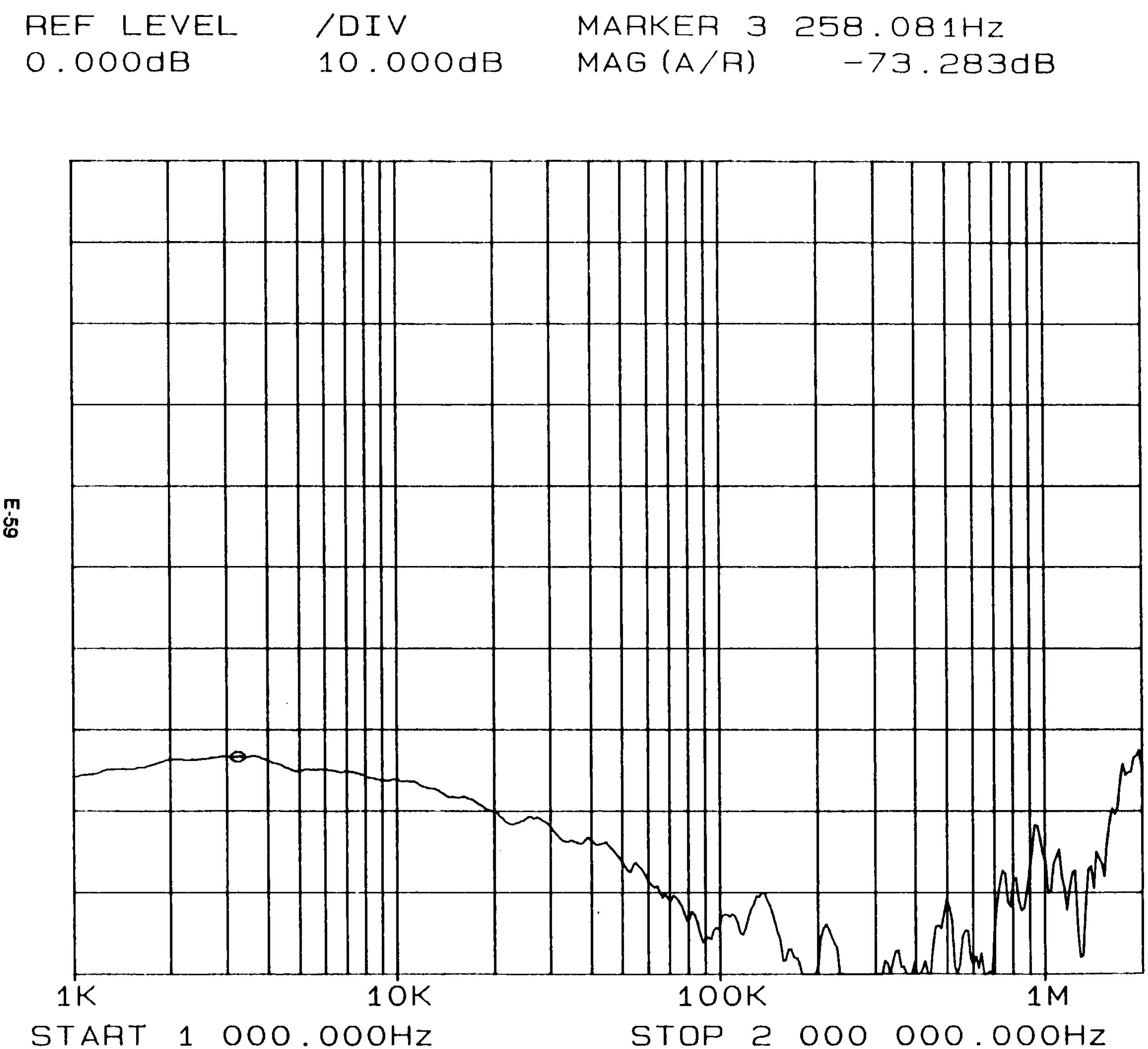
Swept Continuous Wave #70. Attach point #1, Cable #8, Short circuit current, EMI shields closed (subtract 18 dB)

REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -54.345dB



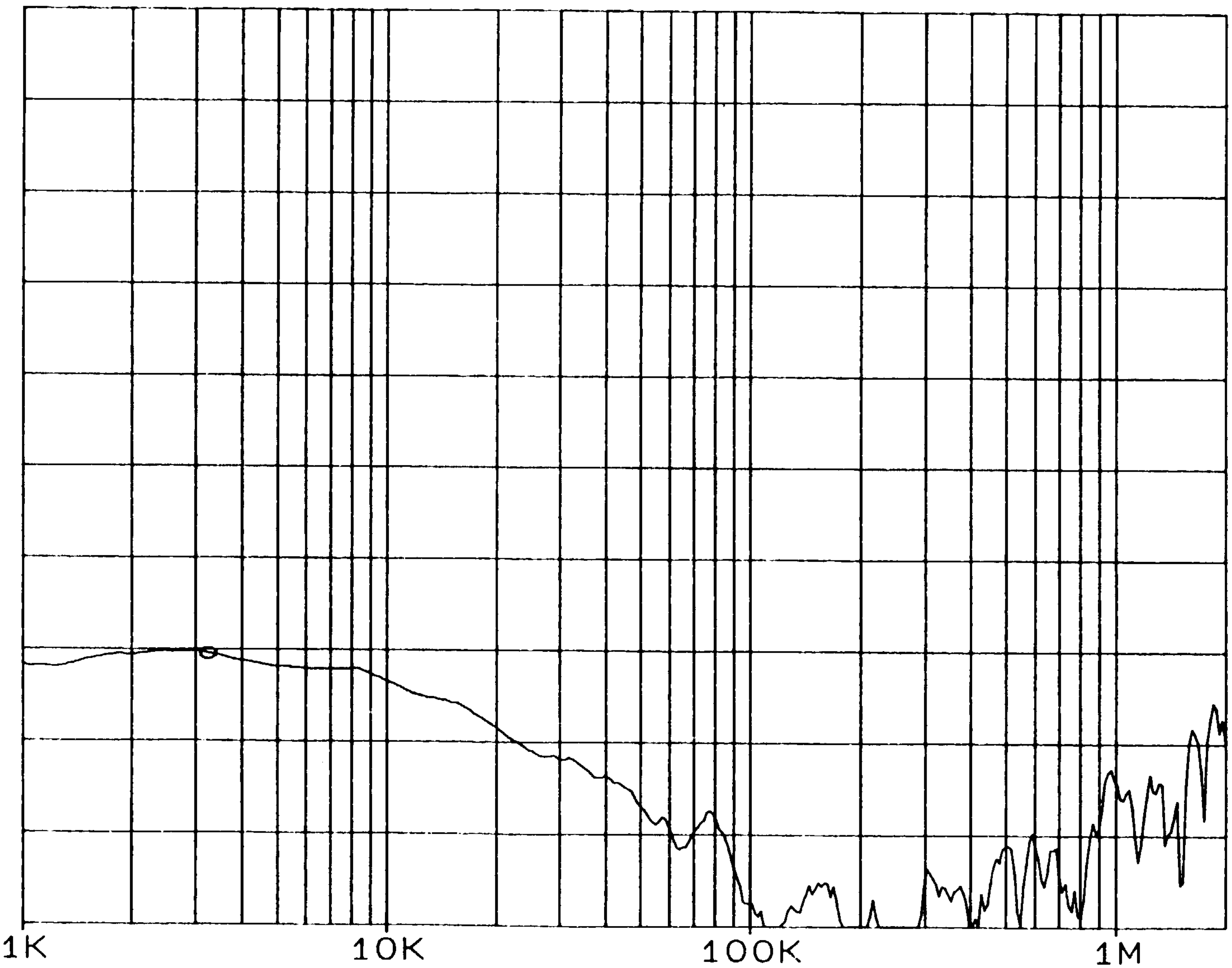
START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #71, Attach point #1, Cable #10, Short circuit current, EMI shields closed (subtract 18 dB)



Swept Continuous Wave #72, Attach point #1, Cable #8, Open circuit voltage, EMI shields closed (subtract 18 dB)

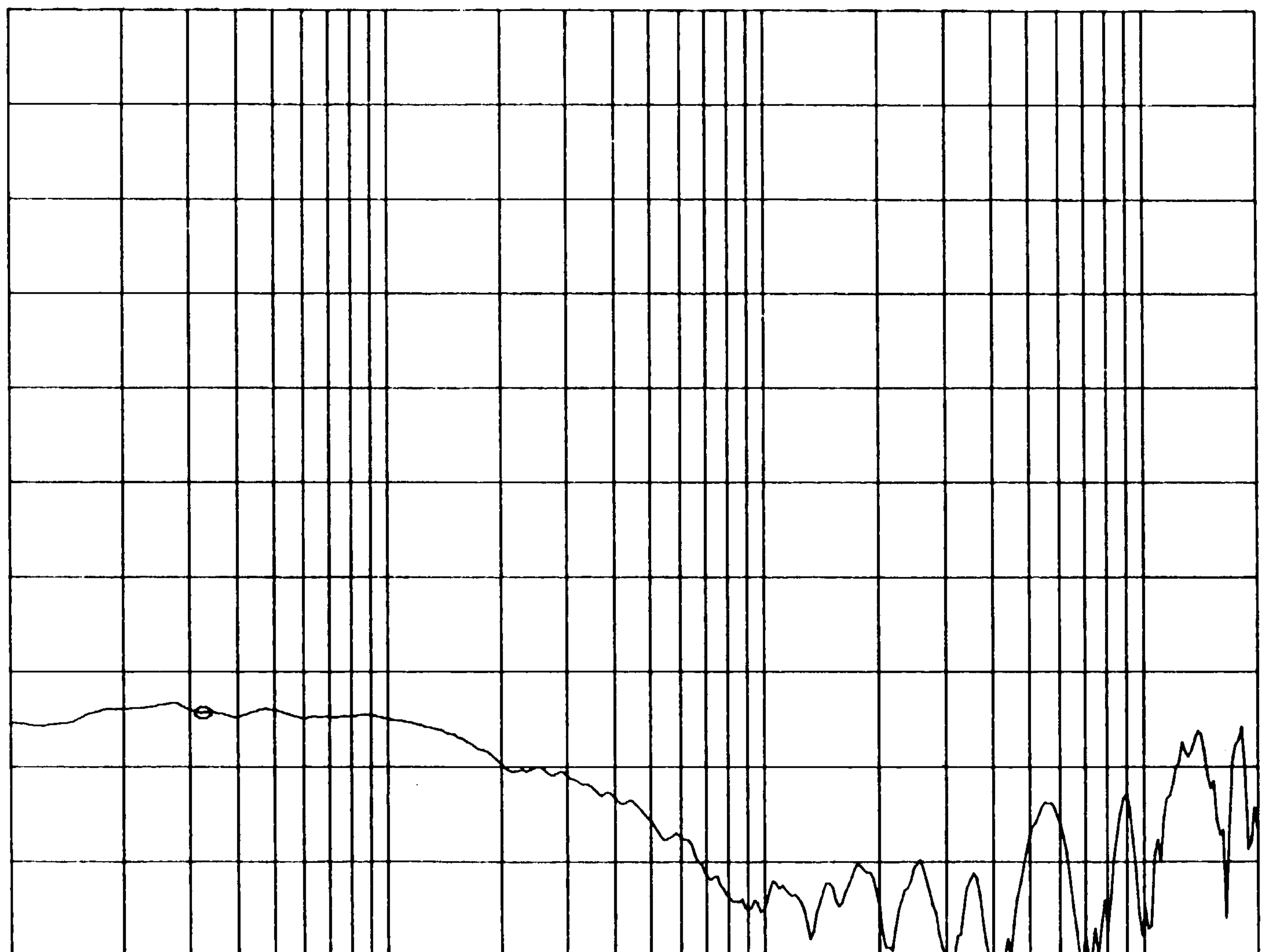
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -70.378dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #73, Attach point #1, Cable #10, Open circuit voltage.
EMI shields closed (subtract 18 dB)

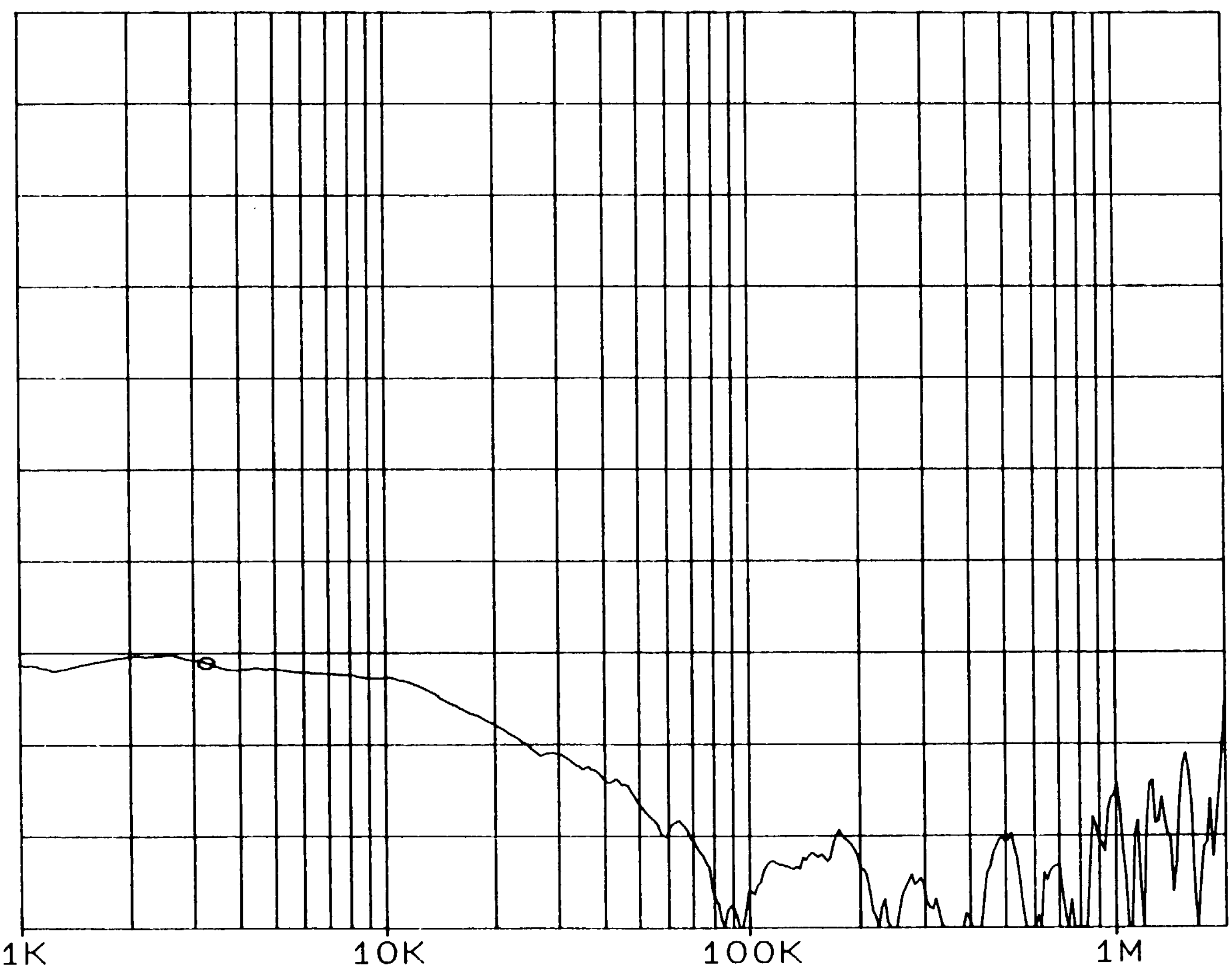
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (A/R) -74.289dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #74, Attach point #3, Cable #8, Open circuit voltage, EMI shields closed (subtract 18 dB)

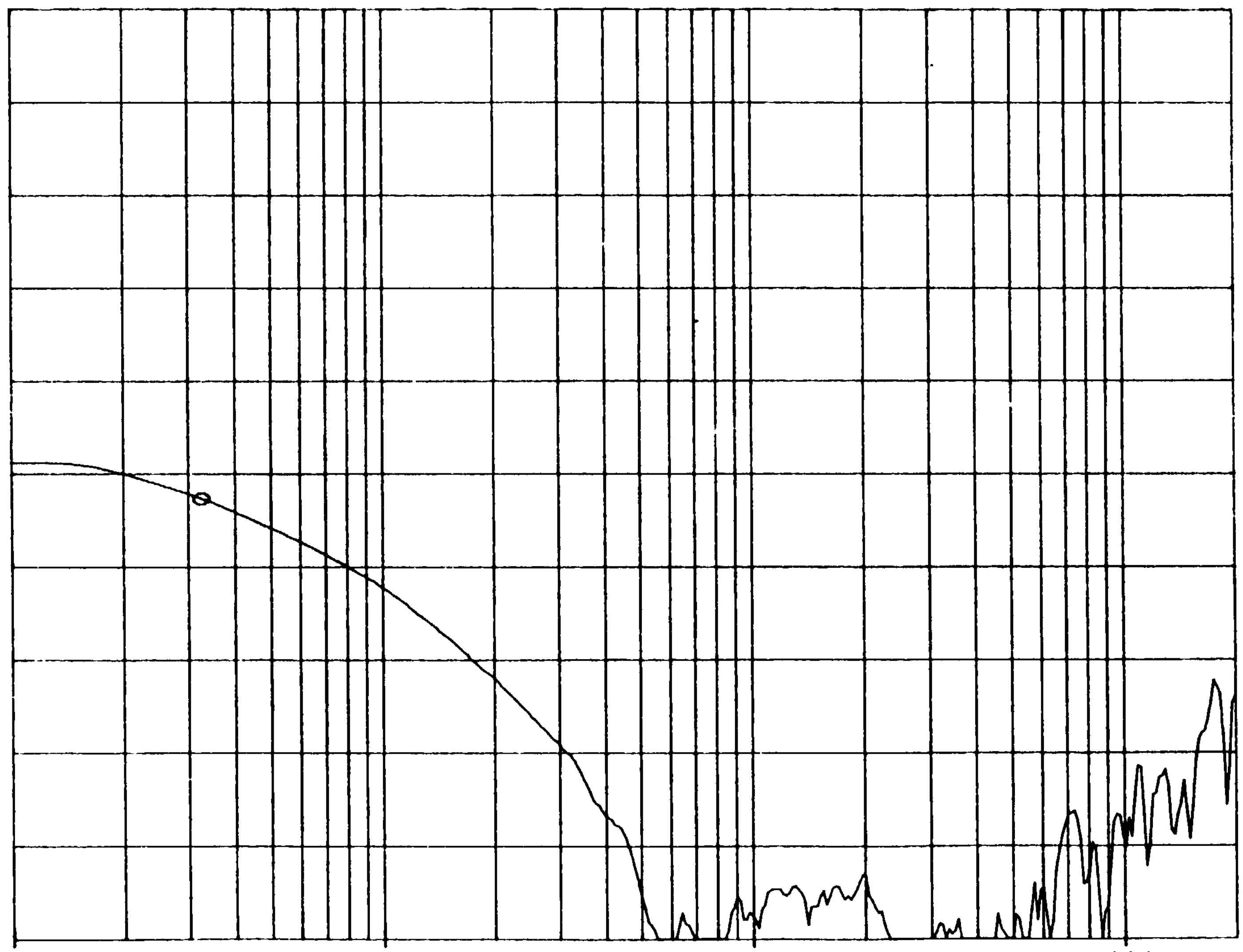
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -71.073dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #75, Attach point #3, Cable #10, Open circuit voltage, EMI shields closed (subtract 18 dB)

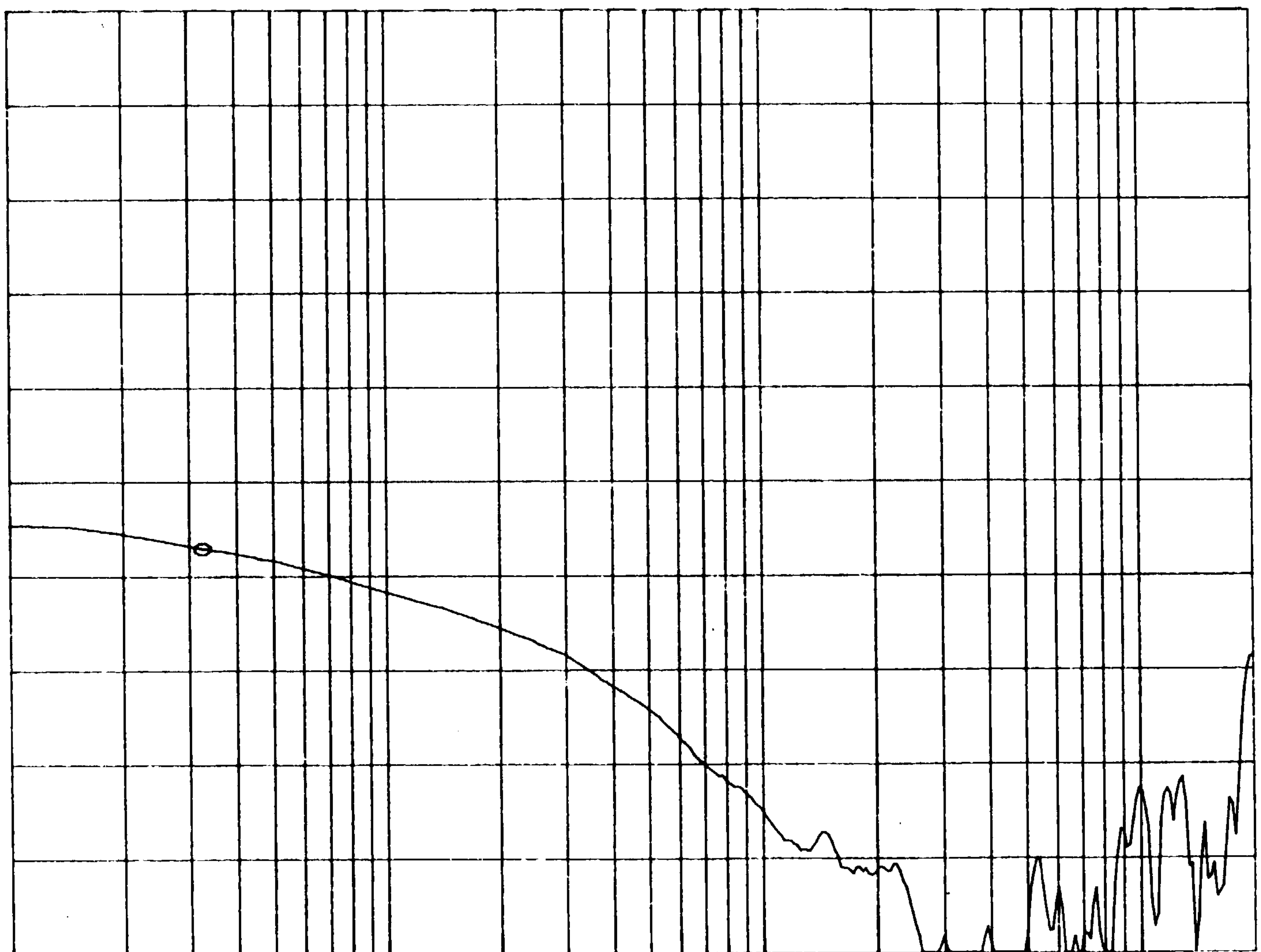
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (A/R) -52.644dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #76, Attach point #3, Cable #8, Short circuit current, EMI shields closed (subtract 18 dB)

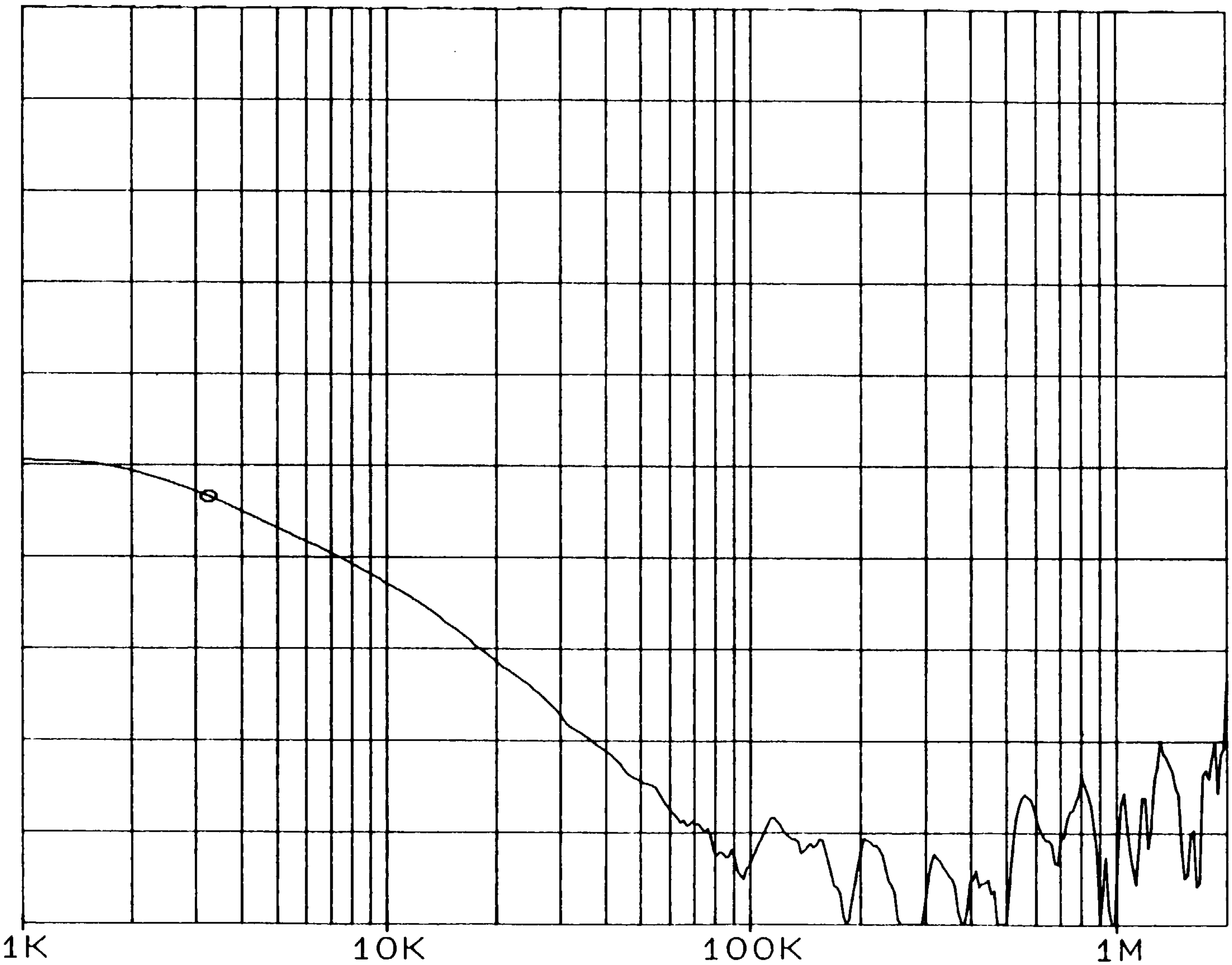
REF LEVEL 0.000dB | /DIV 10.000dB | MARKER 3 258.081Hz | MAG (B/R) -57.067dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #77, Attach point #3, Cable #10, Short circuit current, EMI shields closed (subtract 18 dB)

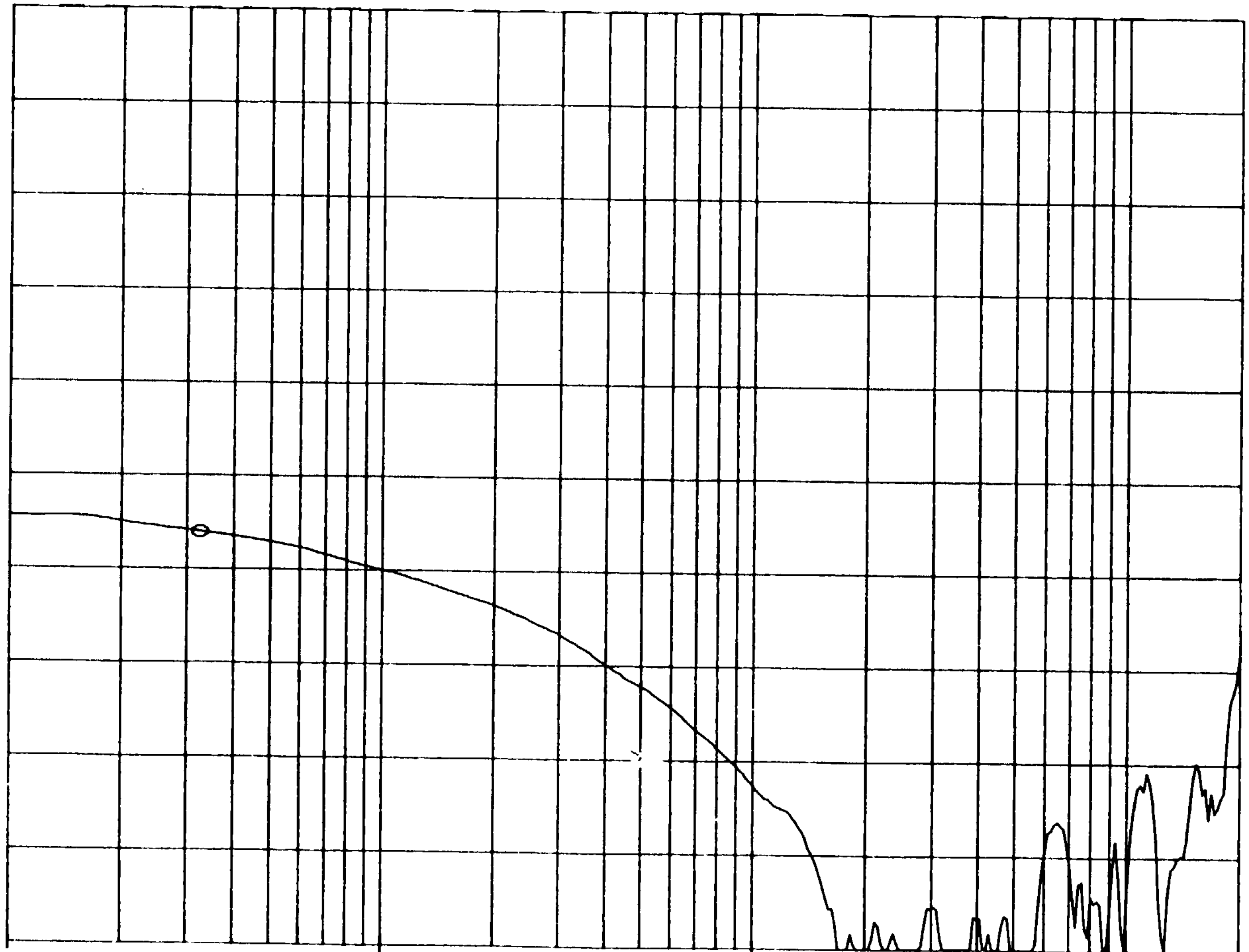
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (A/R) -53.436dB



START 1 000.000Hz STOP 2 000 000.000Hz

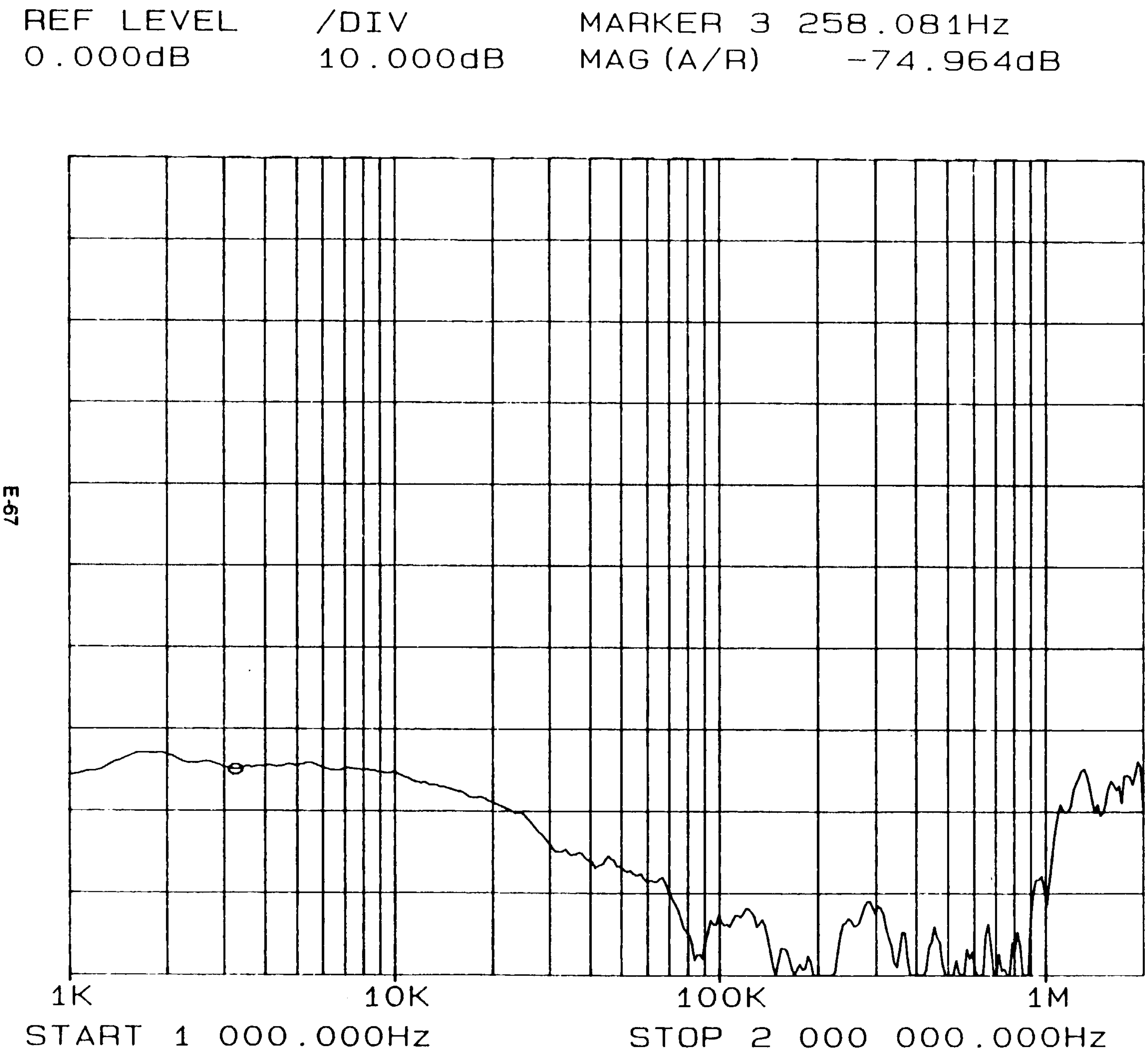
Swept Continuous Wave #78, Attach point #3, Cable #7, Short circuit current, EMI shields closed (subtract 18 dB)

REF LEVEL 0.000dB /DIV 10.000dB MARKER 3 258.081Hz MAG (B/R) -56.026dB



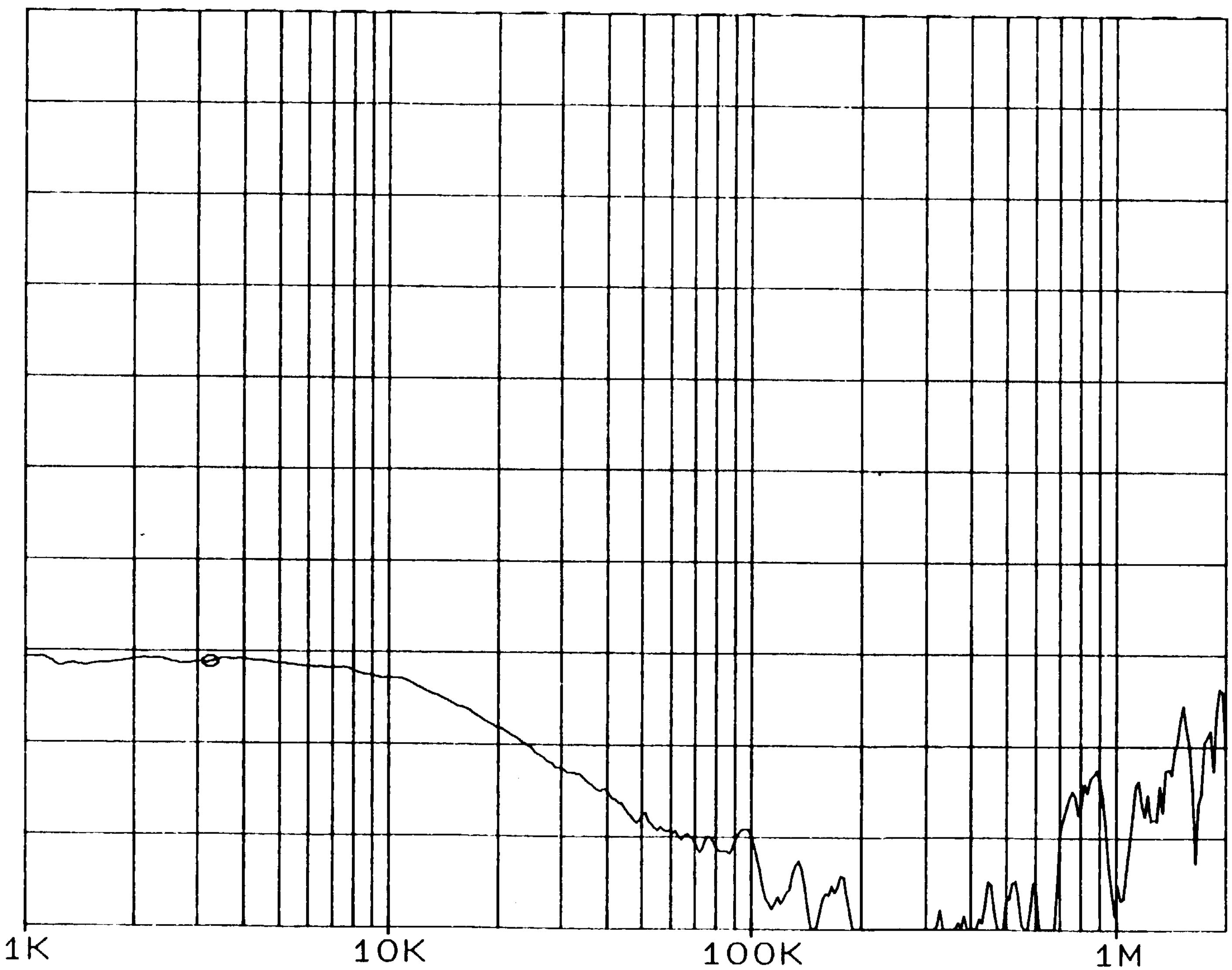
START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #79, Attach point #3, Cable #11, Short circuit current, EMI shields closed (subtract 18 dB)



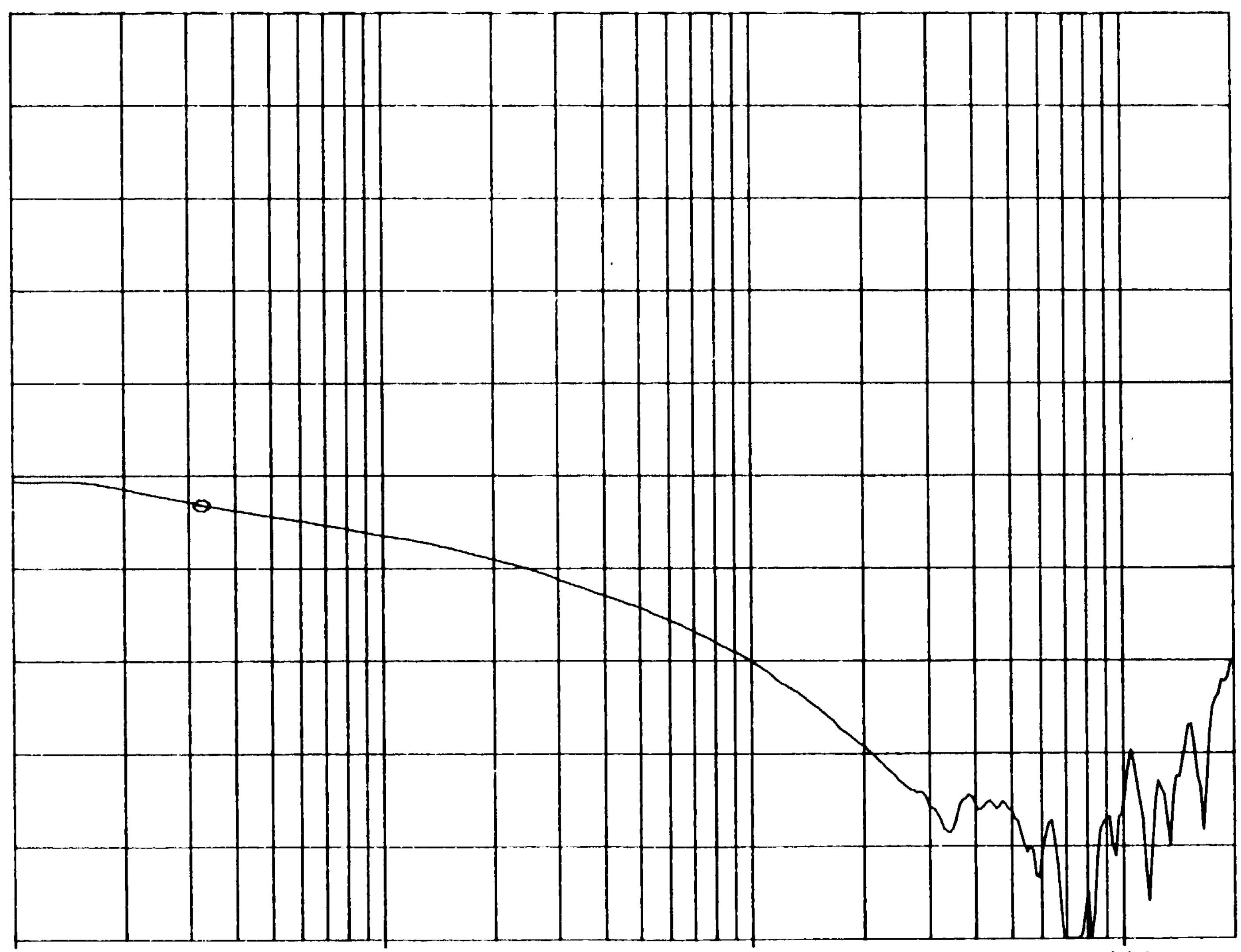
Swept Continuous Wave #80, Attach point #3, Cable #7, Open circuit voltage, EMI shields closed (subtract 18 dB)

REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -71.180dB



START 1 000.000Hz STOP 2 000 000.000Hz
Swept Continuous Wave #81, Attach point #3, Cable #11, Open circuit voltage, EMI shields closed (subtract 18 dB)

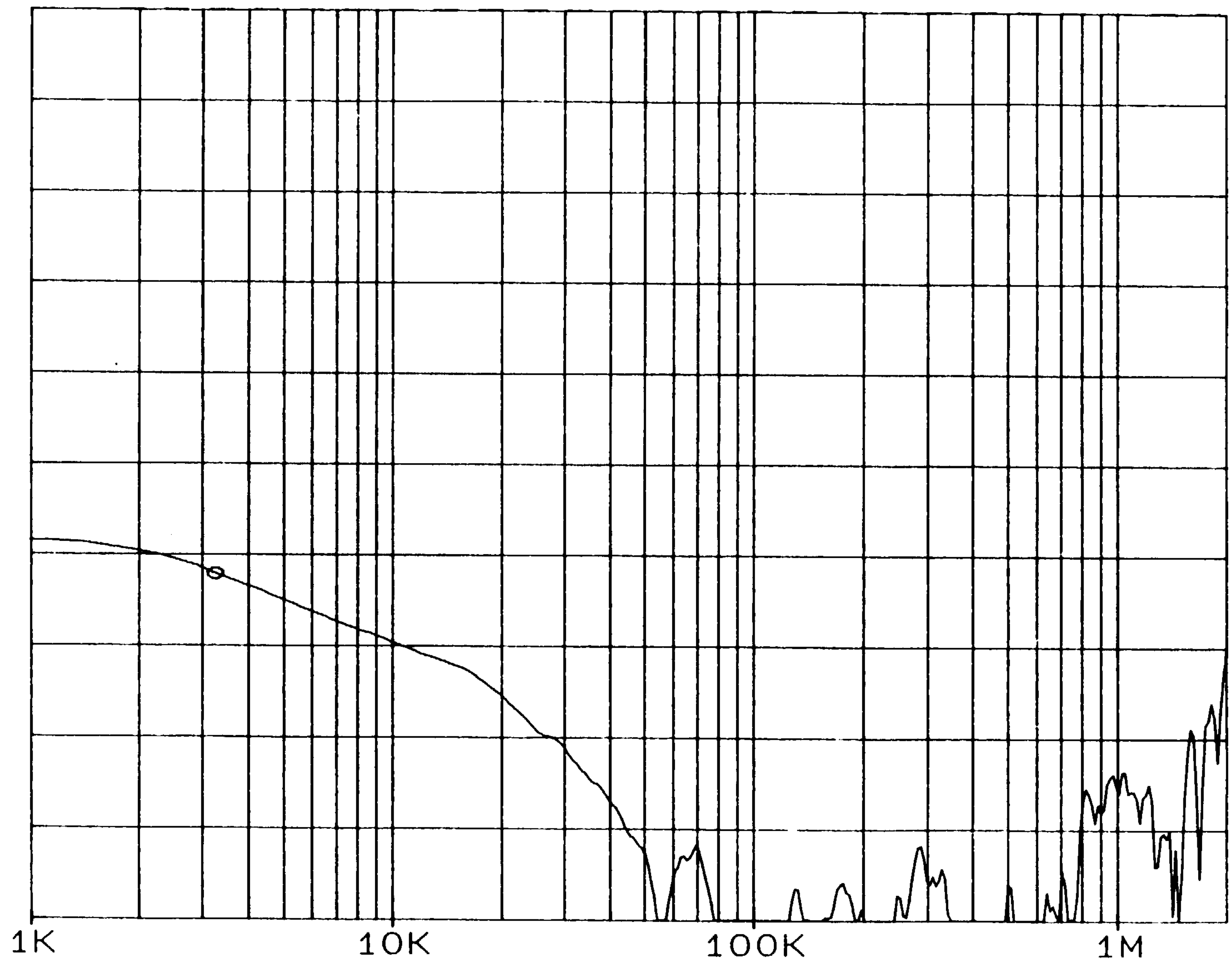
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (A/R) -53.206dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #82, Attach point #3, Cable #6, Short circuit current, EMI shields closed (subtract 18 dB)

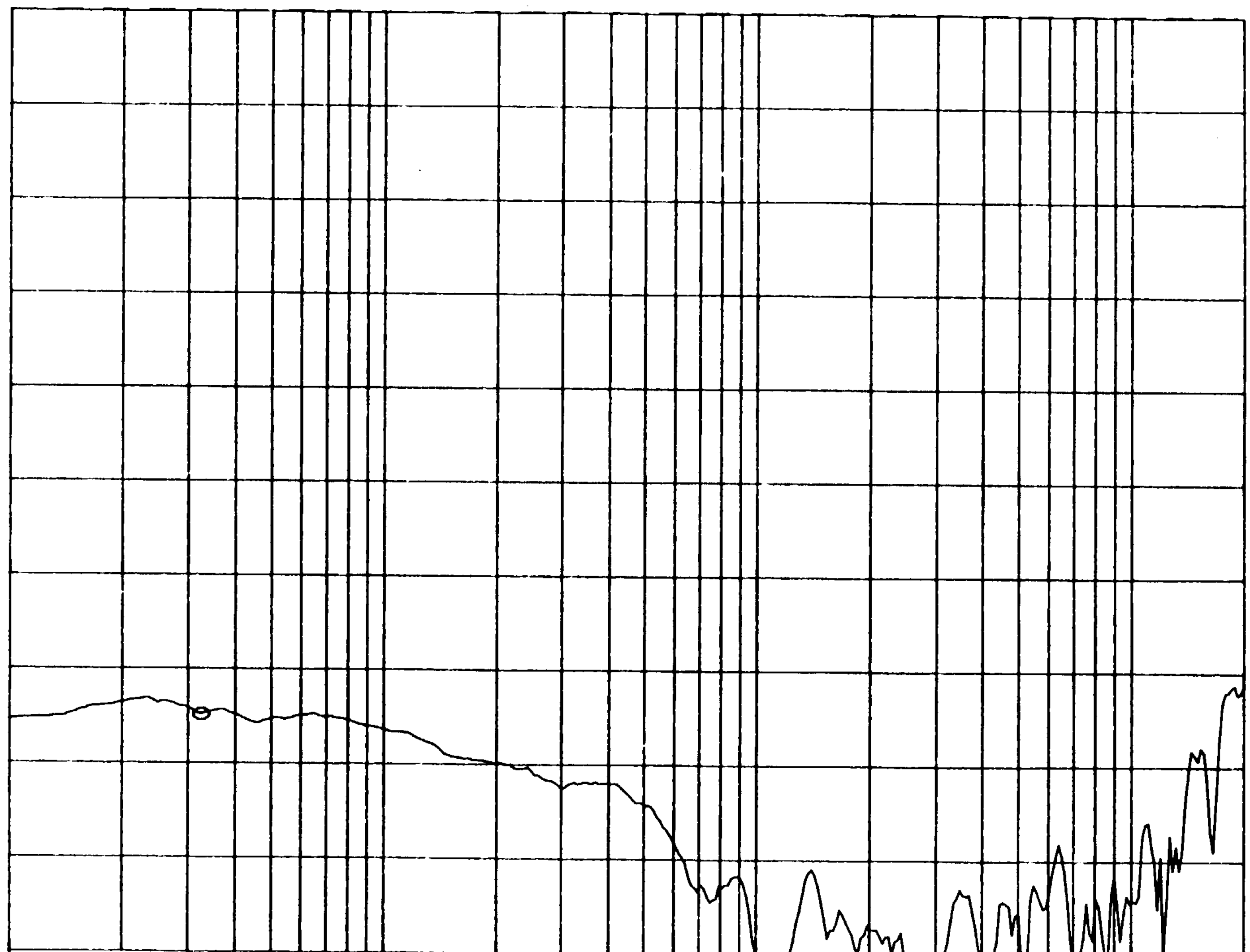
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -62.095dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #83, Attach point #3, Cable #12, Short circuit current, EMI shields closed (subtract 18 dB)

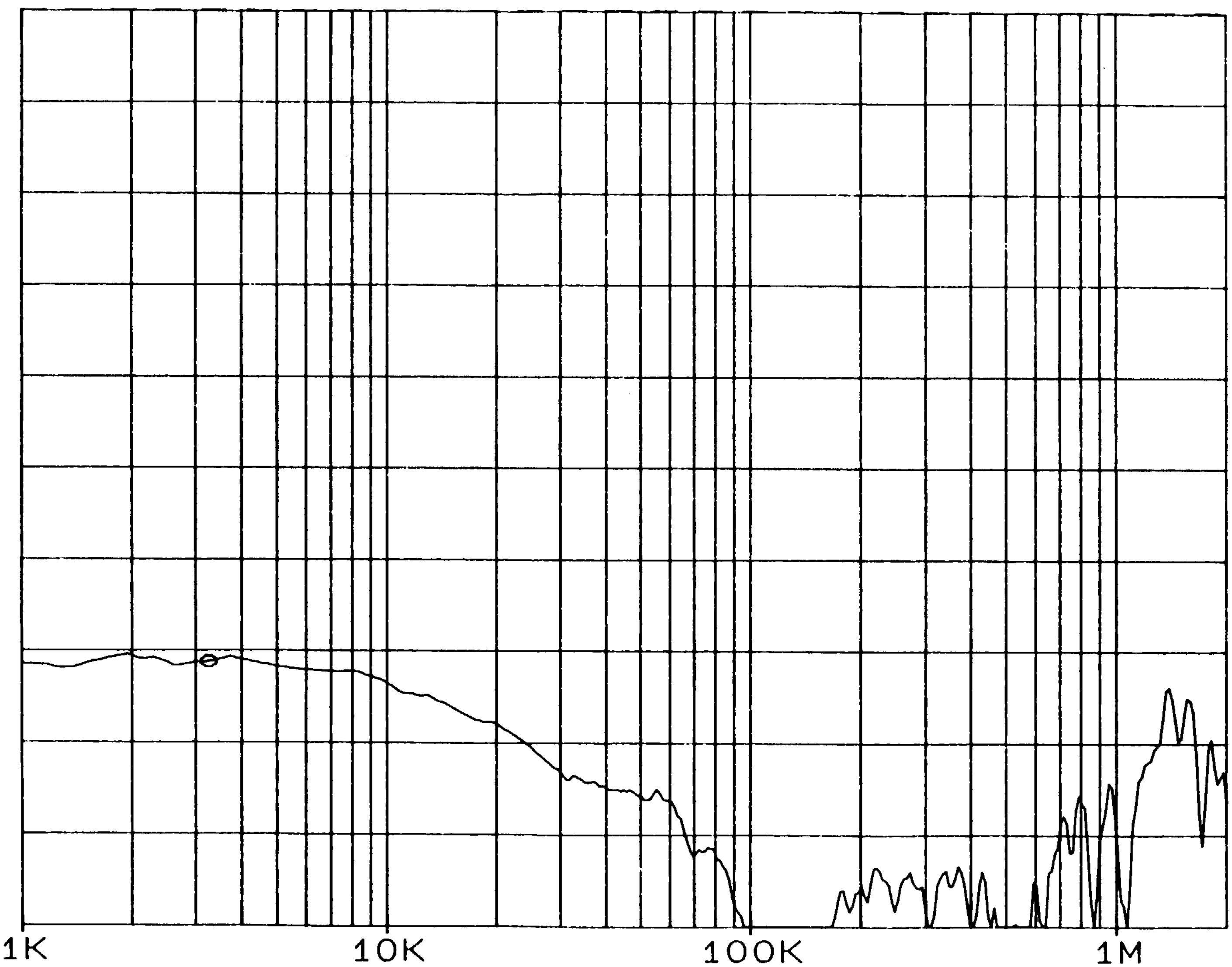
REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (A/R) -74.834dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #84, Attach point #3, Cable #6, Open circuit voltage, EMI shields closed (subtract 18 dB)

REF LEVEL /DIV MARKER 3 258.081Hz
0.000dB 10.000dB MAG (B/R) -71.207dB



START 1 000.000Hz STOP 2 000 000.000Hz

Swept Continuous Wave #85, Attach point #3, Cable #12, Open circuit voltage, EMI shields closed (subtract 18 dB)

Appendix F

USBI Cable Coupling Responses, EMA Final Test Report

EMA-90-R-40
FINAL

EMA ELECTRO MAGNETIC APPLICATIONS, INC.
P.O. Box 260263
Denver, CO 80226-2091
(303) 980-0070

LIGHTNING TEST RESULTS FOR THE MODIFIED SYSTEMS TUNNEL BONDING ON THE SPACE SHUTTLE SOLID ROCKET BOOSTER

Prepared by:

John D. Curry
Calvin C. Easterbrook

Prepared for:

Thiokol Corporation
Space Operations
Attn: Mr. Joe Godfrey M/S E62C
P.O. Box 707
Brigham City, Utah 84302-0707

Prepared Under Prime Contract No. NAS8-30490/P.O. No. ORK022

August 1, 1990

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONT'D.)

LIST OF TABLES

INTRODUCTION

The focus of this report is the issue of peak short-circuit currents and open-circuit voltages induced by lightning on six of the cables within the systems tunnel of the Space Shuttle Solid Rocket Booster (SRB). These six cables will be referred to as cables 6, 7, 8, 10, 11 and 12, according to the numbering scheme as presented in a previous report [1, pages 2-7 and 2-8]. If the induced peak cable transients are below certain specified values, then the instrumentation and other electronic gear or micro-processors that the cables are connected to will not be damaged or a logic upset induced.

Chapter 1 presents the results of the threat level testing, using the same facility at Wendover, Utah as was used for previous testing [1], incorporating recent changes to the hardware and data acquisition system and software [2]. These tests used two capacitor banks, the Marx bank and the High Current Bank, and were conducted by Thiokol Corporation of Brigham City, Utah, and Electro Magnetic Applications (EMA) of Lakewood, Colorado for United Space Boosters Incorporated (USBI) of Huntsville, Alabama. The results of this testing are presented in tables giving peak cable short circuit currents and open circuit voltages that have been normalized linearly to a standard peak injection current.

Also performed at the Wendover facility were a series of low level tests called swept continuous wave (swept CW) which determine the linear response of a system over a frequency range. Instead of tabulating the cable responses at different frequencies in order to conclude something about the threat a lightning strike to the SRB would make to its electronics, a different approach was used in Chapter 2. There, the swept CW result (a frequency transfer function of cable response per injected current) is used with the NASA lightning specification waveform [3] and standard Fourier analysis techniques to determine time domain peak cable responses.

CHAPTER 1

TABULATION OF CABLE RESPONSES TO THREAT LEVEL LIGHTNING TESTING

Table 1.1 lists the peak short circuit cable currents for the High Current Bank shots. Six cables are listed (6, 7, and 8 for the forward tunnel, 10, 11 and 12 for the aft tunnel), and for this and the remaining tables there are six injection points on the SRB for the lightning channel attachment point, namely (1) Forward Tunnel Cover, (2) Station 539 Forward, (3) Case, (4) Aft Tunnel Cover, 3 ft. aft of the ET Ring, (5) Station 1701, external cable, and (6) Heater Connection to ET Ring, 5 milliohm bonding. Also listed for this table only are tests that were made for the external bond straps (BS).

Figure 1.1 shows a typical High Current Bank injection current. It has a bipolar (ringing) waveform, and induces much the same waveform on the cables, as can be seen in Figure 1.2. Table 1.1 lists the peak of this waveform as -70.98 kilo-amperes, and its action integral as 1.149 (mega-amperes)-(seconds squared). Then listed are the shot and plot numbers, where each shot number usually has three plot numbers, one for the injected current, and one each for the forward and aft tunnel cables which are paired as (6,12), (7,11), and (8,10). Finally, there is the cable's short circuit current and plot number, and its value linearly scaled to 200 kilo-amperes injected current. The manner in which one scales the cable's short circuit current linearly to a 200 kilo-ampere (KA) injected current is to divide 200 KA by the injected current and then multiply by the cable's short circuit current. For instance, the very first entry in Table 1.1 (plot #184, shot #49) has peak injected current 66.35 KA and cable current 36.16 amps, so the scaled cable current is (200 KA/66.35 KA) X 36.16 amps = 109 amps.

Table 1.2 lists for the Marx bank shots the same quantities that Table 1.1 did for the High Current bank, with the addition of the peak derivative (DI/DT) in units of kilo-amperes per microsecond. Figure 1.3 shows a typical Marx bank injection current, which also has a ringing waveform. Some of the induced short circuit cable currents had some late-time noise spikes, such as Figure 1.4, and therefore the peak response is an estimated value such as 0.24 amperes for this case.

Table 1.3 lists for the High Current bank shots the peak open circuit cable voltages.

Table 1.4 lists for the Marx bank shots the peak open circuit cable voltages. Many of these have very small and noisy signals, as can be seen in Figure 1.5.

Table 1.5 shows the peak responses for the short circuit cable currents. The first column gives the cable number, and the second column gives the peak High Current Bank short circuit cable currents for injection point 1 (forward tunnel cover), scaled to 200 KA injected current (see last column of Table 1.1). The third and fourth

COMPOSITE CURRENT BANK: HIGH CURRENT

DATE: 05/18/90

TIME: 11: 54: 47.52

datap FILE: H_CHAN1.045 INJECTION, NET SYSTEM GAIN = -42dB

MAX CURRENT = -7.098E4

ACTION INTEGRAL = 1.149E6

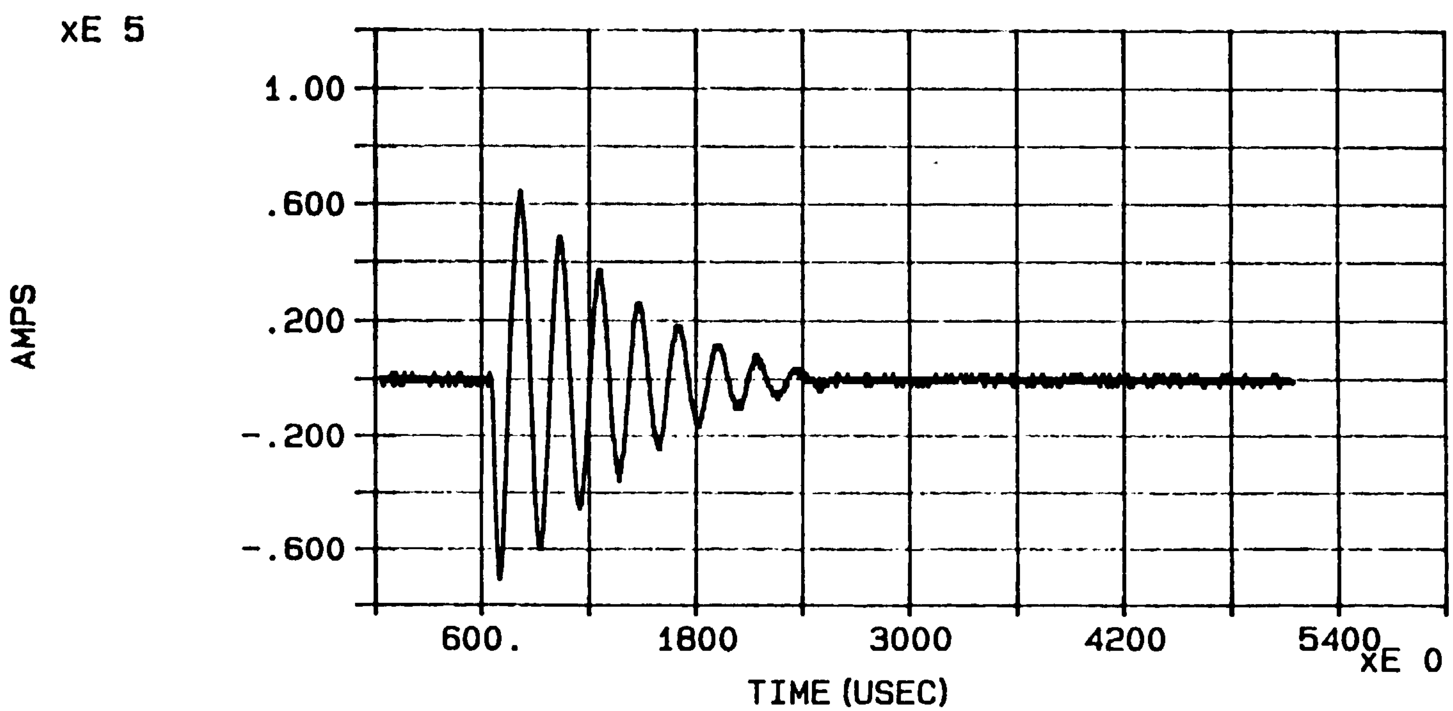


Figure 1.1 Typical High Current Bank Injected Current Waveform. Shot #45, Plot #172, Injection Point #3 (Case)

P2100 PROBE

DATE: 05/18/90

TIME: 12: 04: 44.07

datap FILE: H_CHAN3.045 CABLE # 7, NET SYSTEM GAIN = -36 dB

SHORT CIRCUIT

MAX CURRENT = -2.466E1

ACTION INTEGRAL = 7.224E-2

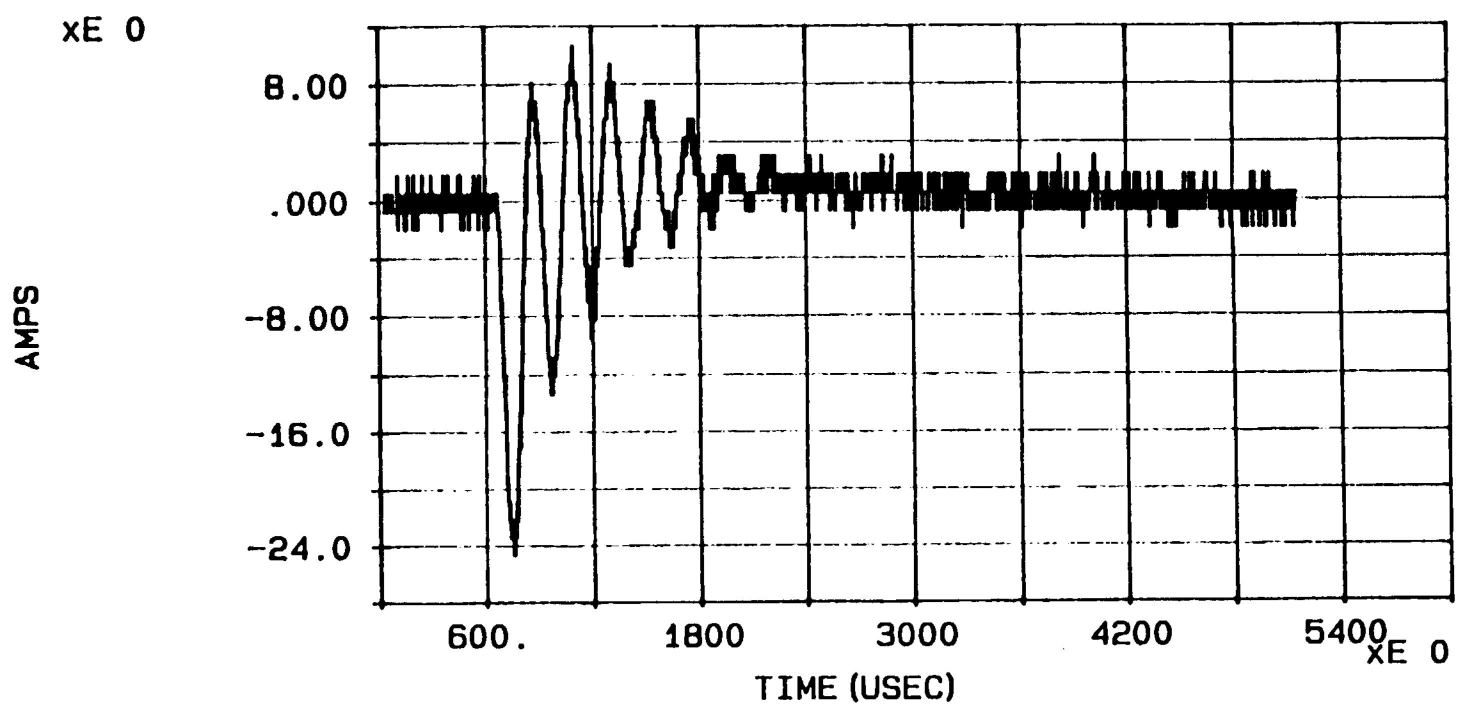


Figure 1.2 Cable #7 Short Circuit Current for the Injected Current of Figure 1.1. Shot #45, Plot #174

Table 1.1

Peak Short Circuit Cable Currents for High Current Bank Shots

Cable #	Inject. Point	HCB Max (KA)	HCB AI (MA-sec^2)	Plot #	Shot #	Cable SCC (Amps)	Plot #	Scaled to 200 KA Inj. (Amps)
6	1	-66.35	0.9503	184	49	-36.16	186	109
6	1	75.71	1.458	235	67	-35.01	237	-92.4
6	2	-64.52	0.6848	202	55	-33.24	204	103
6	3	-77.90	1.115	166	43	-34.96	168	89.6
6	3	73.94	1.321	226	64	-33.36	228	-90.4
6	4	-75.84	1.246	238	68	9.795	240	-25.8
6	BS	-74.33	1.144	XXX	78	-9.383	XXX	25.2
6	BS	-72.92	1.119	XXX	79	32.68	XXX	-89.6
6	BS	-84.39	1.998	XXX	80	34.90	XXX	-82.8
6	BS	73.31	1.166	XXX	81	-24.47	XXX	-66.8
6	BS	100.9	2.194	XXX	82	-18.88	XXX	-37.4
6	BS	85.37	1.485	XXX	83	-25.48	XXX	-59.6
6	BS	99.39	2.132	XXX	84	-25.79	XXX	-52.0
6	BS	91.88	1.865	XXX	85	-31.66	XXX	-68.8
6	BS	98.53	2.197	XXX	86	-49.01	XXX	-99.6
6	BS	96.04	2.006	XXX	87	-56.98	XXX	-119
6	BS	105.0	2.469	XXX	88	8.687	XXX	16.6
6	BS	101.3	2.191	XXX	89	6.140	XXX	12.1
6	BS	107.6	2.449	XXX	91	3.045	XXX	5.64
6	BS	85.50	1.290	XXX	92	-24.29	XXX	-56.8
6	BS	-102.9	1.805	XXX	93	-31.35	XXX	60.8
6	BS	-106.8	1.778	XXX	96	-39.33	XXX	73.6
6	BS	-98.36	2.250	XXX	97	11.23	XXX	-22.8
6	BS	-91.96	1.880	XXX	98	12.56	XXX	-27.3
6	BS	-99.27	2.200	XXX	100	7.403	XXX	-14.9
6	BS	-121.0	4.556	XXX	101	8.668	XXX	-14.3
6	BS	133.0	4.580	XXX	102	7.886	XXX	11.8
6	BS	-84.47	1.535	XXX	103	-5.600	XXX	13.2
6	BS	128.3	4.208	XXX	104	-8.934	XXX	-13.9
6	BS	128.8	4.515	XXX	105	-41.88	XXX	-65.2
6	BS	-96.81	2.234	XXX	106	40.02	XXX	-82.8
6	BS	113.2	3.353	XXX	107	41.39	XXX	73.2
6	BS	-106.2	2.374	XXX	108	-34.18	XXX	64.4
7	1	-71.88	1.212	190	51	-22.28	192	62.0
7	1	-76.12	1.143	220	62	-14.13	222	37.1
7	1	74.50	1.312	232	66	13.39	234	36.0
7	2	-63.87	0.6586	205	56	-22.74	207	71.2
7	3	-70.98	1.149	172	45	-24.66	174	69.6
7	3	-70.47	1.178	223	63	-24.36	225	69.2
7	3	71.53	1.323	229	65	-21.91	231	-61.2
7	4	-75.72	1.302	214	60	6.044	216	-16.0
7	4	-77.52	1.338	241	69	5.663	243	-14.6
7	5	-65.61	0.7864	217	61	-2.895	219	8.84
8	1	-71.66	1.256	196	53	-31.70	198	88.4
8	3	-69.10	1.116	178	47	-33.71	180	97.6
10	1	-71.66	1.256	196	53	9.964	197	-27.8
10	3	-69.10	1.116	178	47	14.66	179	-42.4
10	4	-69.83	1.020	212	59	-34.00	213	97.2

Table 1.1 (Cont'd.)

Peak Short Circuit Cable Currents for High Current Bank Shots

Cable #	Inject. Point	HCB Max (KA)	HCB AI (MA-sec^2)	Plot #	Shot #	Cable SCC (Amps)	Plot #	Scaled to 200 KA Inj. (Amps)
11	1	-71.88	1.212	190	51	15.80	191	-44.0
11	1	-76.12	1.143	220	62	22.32	221	-58.8
11	1	74.50	1.312	232	66	12.76	233	34.2
11	2	-63.87	0.6586	205	56	13.17	206	-41.2
11	3	-70.98	1.149	172	45	9.352	173	-26.4
11	3	-70.47	1.178	223	63	26.92	224	-76.4
11	3	71.53	1.323	229	65	13.98	230	39.1
11	4	-75.72	1.302	214	60	-68.51	215	181
11	4	-77.31	1.325	210	58	-37.76	211	97.6
11	4	-77.52	1.338	241	69	-36.40	242	94.0
11	5	-65.61	0.7864	217	61	-4.821	218	14.7
12	1	-66.35	0.9503	184	49	7.698	185	-23.2
12	1	75.71	1.458	235	67	7.094	236	18.8
12	2	-64.52	0.6848	202	55	7.679	203	-23.8
12	3	-77.90	1.115	166	43	9.818	167	-25.2
12	3	73.94	1.321	226	64	8.252	228	22.3
12	4	-77.69	1.332	208	57	-29.15	209	74.4
12	4	-75.84	1.246	238	68	-28.08	239	74.0
12	BS	-74.33	1.144	XXX	78	8.858	XXX	-23.8
12	BS	-72.92	1.119	XXX	79	6.528	XXX	-17.9
12	BS	-84.39	1.998	XXX	80	8.140	XXX	-19.3
12	BS	73.31	1.166	XXX	81	7.158	XXX	19.5
12	BS	100.9	2.194	XXX	82	7.322	XXX	14.5
12	BS	85.37	1.485	XXX	83	5.594	XXX	13.1
12	BS	99.39	2.132	XXX	84	7.540	XXX	15.2
12	BS	91.88	1.865	XXX	85	7.310	XXX	15.9
12	BS	98.53	2.197	XXX	86	9.071	XXX	18.4
12	BS	96.04	2.006	XXX	87	10.40	XXX	21.6
12	BS	105.0	2.469	XXX	88	-10.20	XXX	-19.4
12	BS	101.3	2.191	XXX	89	-9.400	XXX	-18.6
12	BS	107.6	2.449	XXX	91	2.406	XXX	4.48
12	BS	85.50	1.290	XXX	92	9.355	XXX	21.9
12	BS	-102.9	1.805	XXX	93	12.13	XXX	-23.6
12	BS	-106.8	1.778	XXX	96	8.489	XXX	-15.9
12	BS	-98.36	2.250	XXX	97	7.125	XXX	-14.5
12	BS	-91.96	1.880	XXX	98	4.972	XXX	-10.8
12	BS	-99.27	2.200	XXX	100	12.50	XXX	-25.2
12	BS	-121.0	4.556	XXX	101	-12.43	XXX	20.6
12	BS	133.0	4.580	XXX	102	6.025	XXX	9.08
12	BS	-84.47	1.535	XXX	103	14.96	XXX	-35.4
12	BS	128.3	4.208	XXX	104	22.32	XXX	34.8
12	BS	128.8	4.515	XXX	105	14.07	XXX	21.8
12	BS	113.2	3.353	XXX	107	-58.91	XXX	-104
12	BS	-106.2	2.374	XXX	108	-6.767	XXX	12.8

Table 1.2

Peak Short Circuit Cable Currents for Marx Bank Shots

Cable #	Inject. Point	Marx Max (KA)	Marx AI (KA-sec^2)	Marx DI/DT (KA/μSEC)	Plot #	Shot #	Cable SCC (Amps)	Plot #	Scaled to 200 KA Inj.(Amps)
6	1	31.08	3.227	133.0	33	9	0.2020	35	1.30
6	1	22.57	2.563	86.84	252	72	1.442	255	12.8
6	3	27.34	2.278	109.1	61	16	0.9209	63	6.74
6	3	22.48	2.394	99.20	264	75	1.008	267	8.97
6	4	21.69	1.482	126.5	90	24	0.03781	92	.349
6	4	31.08	5.912	142.5	248	71	0.1763	251	1.13
6	5	23.34	1.631	118.4	122	32	-.05101	124	-.437
6	5	22.33	1.445	109.1	130	34	-.07271	132	-.651
6	6	20.98	2.107	128.1	268	76	0.2178	271	2.08
7	1	28.71	2.172	161.7	37	10	0.1824	39	1.27
7	1	23.62	1.634	107.8	142	37	0.3464	144	2.93
7	2	23.84	1.586	109.1	154	40	0.4094	156	3.44
7	3	27.54	2.071	127.8	65	17	-.01824	67	-.132
7	3	22.13	1.351	107.8	158	41	0.3540	160	3.20
7	3	21.18	2.073	106.0	260	74	0.2317	263	2.19
7	4	22.47	1.574	126.5	94	25	-.01135	96	-.101
7	4	28.48	2.928	135.9	134	35	0.1111	136	.780
7	4	27.38	4.310	141.2	244	70	-0.1110	247	-.811
7	5	23.48	1.443	121.3	126	33	-.01018	128	-.087
7	6	21.16	2.375	119.7	272	77	0.06685	275	.632
8	1	27.83	2.151	121.3	41	11	0.0555	43	.399
8	3	27.52	2.135	110.4	69	18	0.04664	71	.339
8	4	21.55	1.570	117.2	98	26	0.1462	100	1.36
10	1	27.83	2.151	121.3	41	11	-0.1781	44	-1.28
10	3	27.52	2.135	110.4	69	18	-0.1651	72	-1.20
10	4	21.55	1.570	117.2	98	26	-0.1317	101	-1.22
11	1	28.71	2.172	161.7	37	10	-0.3314	40	-2.31
11	1	23.62	1.634	107.8	142	37	-0.2646	145	-2.24
11	2	23.84	1.586	109.1	154	40	-0.2839	157	-2.38
11	3	27.54	2.071	127.8	65	17	-0.3133	68	-2.28
11	3	22.13	1.351	107.8	158	41	-0.3439	161	-3.11
11	3	21.18	2.073	106.0	260	74	-0.1379	262	-1.30
11	4	22.47	1.574	126.5	94	25	0.25	97	2.23
11	4	28.48	2.928	135.9	134	35	0.1691	137	1.19
11	4	27.38	4.310	141.2	244	70	1.203	246	8.79
11	5	23.48	1.443	121.3	126	33	0.2091	129	1.78
11	6	21.16	2.375	119.7	272	77	-0.1228	274	-1.16
12	1	31.08	3.227	133.0	33	9	0.2445	36	1.57
12	1	22.57	2.563	86.84	252	72	0.2610	254	2.31
12	3	27.34	2.278	109.1	61	16	0.2478	64	1.81
12	3	22.48	2.394	99.20	264	75	0.24	266	2.14
12	4	21.69	1.482	126.5	90	24	0.48	93	4.43
12	4	31.08	5.912	142.5	248	71	2.182	250	14.0
12	5	22.33	1.445	109.1	130	34	0.3224	133	2.89
12	6	20.98	2.107	128.1	268	76	0.63	270	6.01

MARX MEASUREMENT: INPUT CURRENT

DATE: 05/22/90

TIME: 18: 09: 57.53

FILE: m130075

MAX CURRENT = 2.248E4

ACTION INTEGRAL = 2.394E3

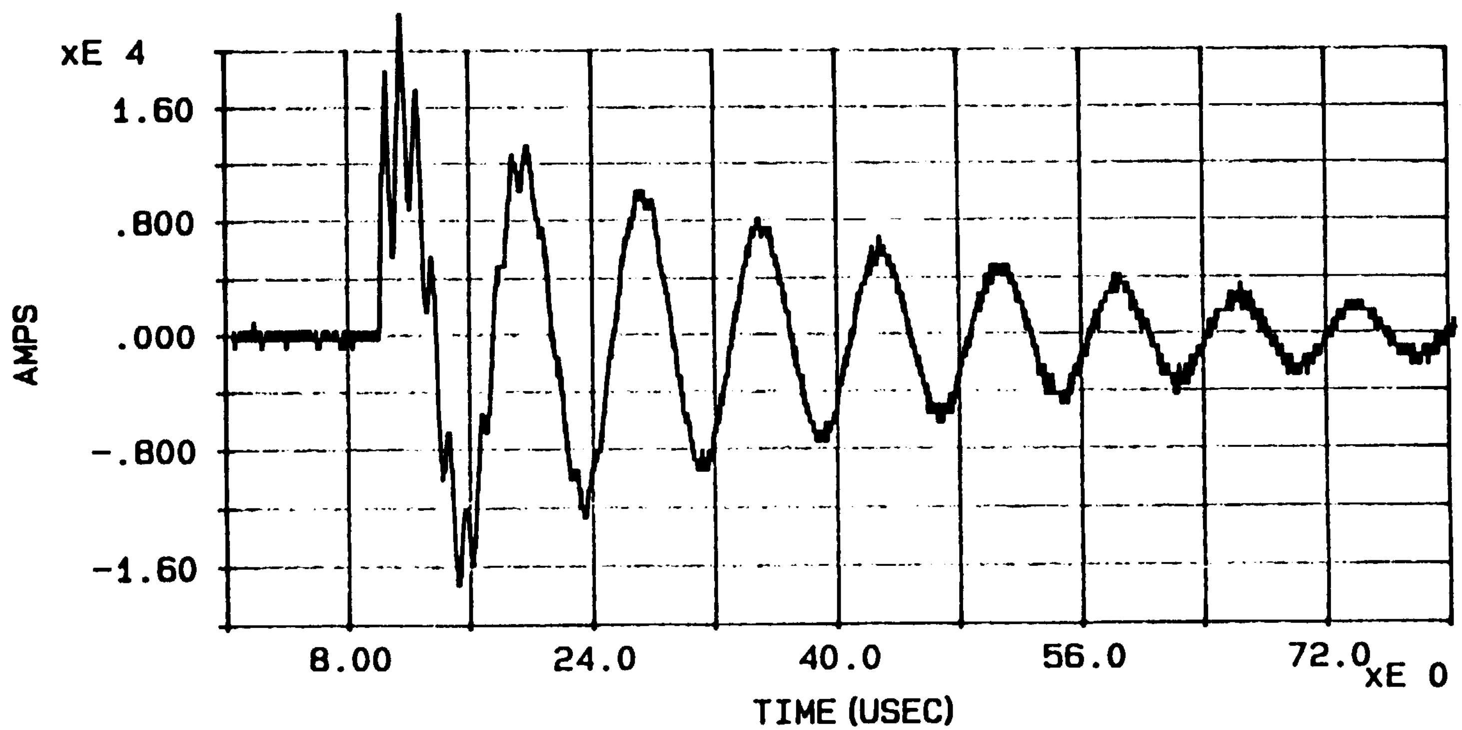


Figure 1.3 Typical Marx Bank Injected Current Waveform. Shot #75, Plot #264, Injection Point #3 (Case)

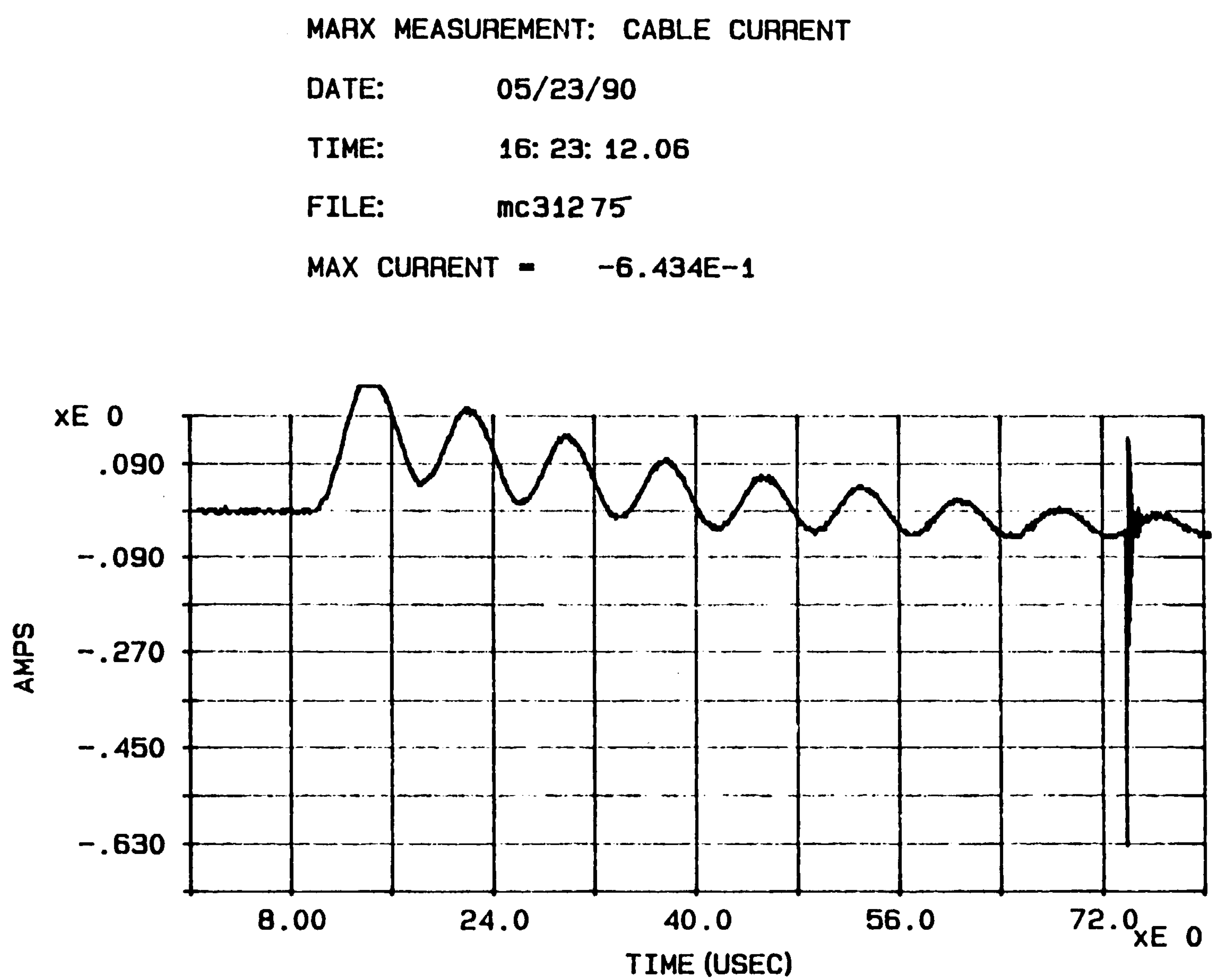


Figure 1.4 Cable #12 Short Circuit Current for the Injected Current of Figure 1.3. Shot #75, Plot #266. Presented to Show Example of Late-Time Noise Spike

Table 1.3

Peak Open Circuit Cable Voltages for High Current Bank Shots

Cable #	Inject. Point	HCB Max (KA)	HCB AI ($MA\text{-}sec^2$)	Plot #	Shot #	Cable VOC (Volts)	Plot #	Scaled to 200 KA Inj. (Volts)
6	1	-72.48	1.161	187	50	7.062	189	-19.5
7	1	-68.23	1.035	193	52	-1.166	195	3.42
8	1	-77.68	1.456	199	54	-3.066	201	7.88
8	3	-69.72	1.148	181	48	-5.967	183	17.1
10	1	-77.68	1.456	199	54	1.474	200	-3.80
10	3	-69.72	1.148	181	48	-2.162	182	6.20
11	1	-68.23	1.035	193	52	1.484	194	-4.36
12	1	-72.48	1.161	187	50	1.344	189	-3.71

Table 1.4

Peak Open Circuit Cable Voltages for Marx Bank Shots

Cable #	Inject. Point	Marx Max (KA)	Marx AI ($KA\text{-}sec^2$)	Marx DI/DT (KA/μsec)	Plot #	Shot #	Cable VOC (Volts)	Plot #	Scaled to 200 KA Inj. (Volts)
6	2	23.10	1.568	94.24	86	23	1.102	88	9.54
6	4	20.51	1.621	99.72	110	29	-0.2234	112	-2.18
6	5	22.83	1.566	130.7	118	31	-0.3384	120	-2.96
7	1	28.37	2.062	127.8	53	14	0.1193	55	.841
7	1	22.70	1.564	91.66	146	38	0.4397	148	3.87
7	2	23.36	1.502	128.1	150	39	-0.5223	152	-4.47
7	3	26.45	2.029	109.1	77	20	-0.2048	79	-1.55
7	3	23.41	1.605	95.53	162	42	0.4	164	3.4
7	4	19.97	1.357	125.2	106	28	-0.3355	108	-3.36
7	4	21.66	1.502	130.7	138	36	0.3557	140	3.28
8	1	27.65	2.066	132.0	49	13	0.1	51	.72
8	3	27.88	2.286	121.3	73	19	-0.2572	75	-1.85
8	4	21.42	1.617	96.82	102	27	0.3269	104	3.05
10	1	27.65	2.066	132.0	49	13	-0.2	51	-1.4
10	3	27.88	2.286	121.3	73	19	-0.25	76	-1.8
10	4	21.42	1.617	96.82	102	27	-0.85	105	-7.9
11	1	28.37	2.062	127.8	53	14	-0.5	56	-3.5
11	1	22.70	1.564	91.66	146	38	-0.42	149	-3.7
11	2	23.36	1.502	128.1	150	39	-0.6	153	-5.1
11	3	26.45	2.029	109.1	77	20	-0.4771	80	-3.61
11	3	23.41	1.605	95.53	162	42	-0.4	165	-3.4
11	4	19.97	1.357	125.2	106	28	-0.6150	109	-6.16
11	4	21.66	15.02	130.7	138	36	0.9	141	8.3
12	2	23.10	1.568	94.24	86	23	0.7	89	6.1
12	4	20.51	1.621	99.72	110	29	0.6	113	5.9
12	5	22.83	1.566	130.7	118	31	1.0	121	8.8

MARX MEASUREMENT: CABLE OC VOLTAGE

DATE: 05/17/90

TIME: 08: 47: 03.29

FILE: C:\ASYST\DATA1\MV40827

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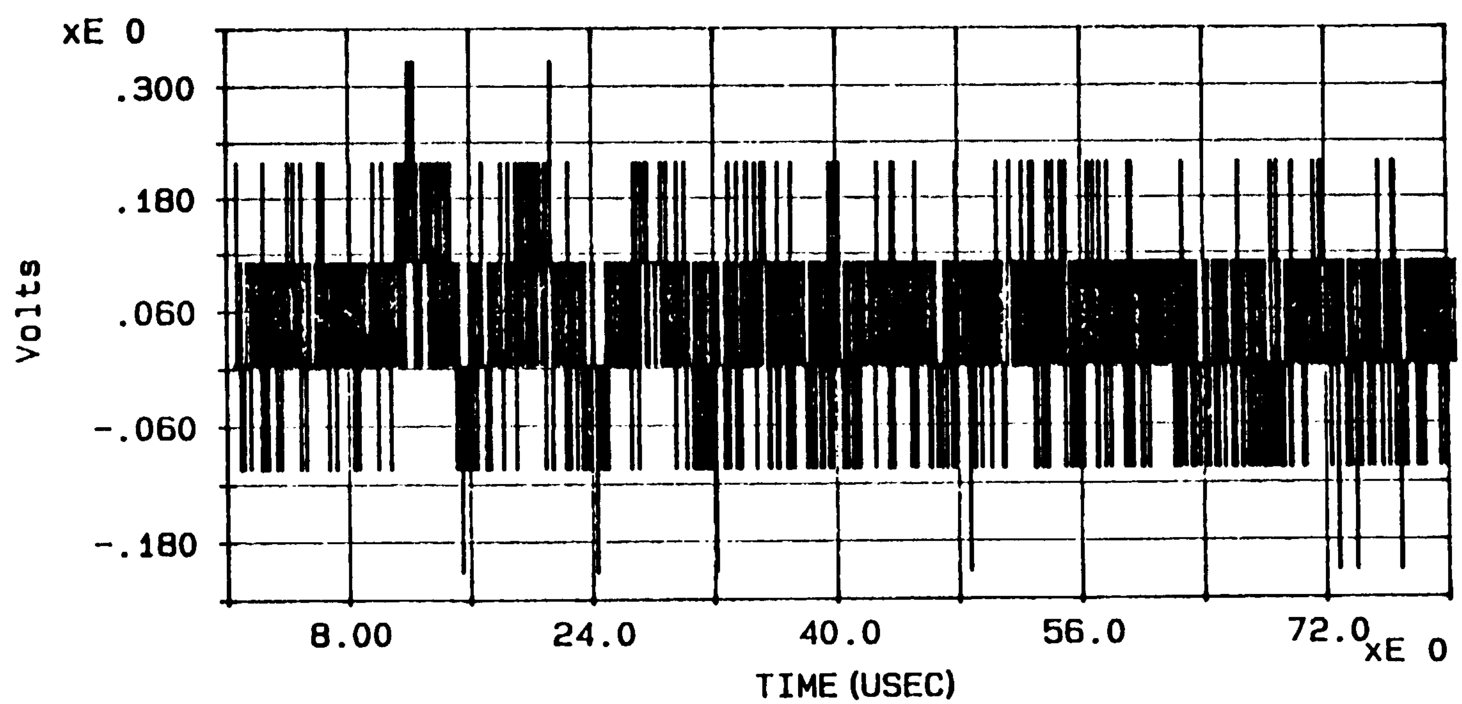


Figure 1.5 Cable #8 Open Circuit Voltage. Shot #27, Plot #104. Injection Point #4 (Aft Tunnel Cover). Presented to Show Example of Noisy Open Circuit Voltage Measurement

Table 1.5

Tabulation of Peak Scaled Short Circuit Cable Currents, Ending With Flight Configuration Cable Currents. Top Row is Column Number for Easy Reference

1 Cable #	2 HCB 1 Amps	3 HCB 3 Amps	4 HCB All Amps	5 Marx 1 Amps	6 Marx 3 Amps	7 Marx All Amps	8 Peak 1 Amps	9 Peak 3 Amps	10 Peak All Amps	11 Flight 1 Amps	12 Flight 3 Amps	13 Flight All Amps	14 Flight Old (3) Amps
6	109	90.4	119	12.8	8.97	12.8	109	90.4	119	110	90	120	83
7	37.1	69.6	71.2	2.93	3.20	3.44	37.1	69.6	71.2	37	70	71	30
8	88.4	97.6	97.6	0.399	0.339	1.36	88.4	97.6	97.6	88	98	98	93
10	27.8	42.4	97.2	1.28	1.20	1.28	27.8	42.4	97.2	56	85	190	46
11	58.8	39.1	181	2.31	3.11	8.79	58.8	39.1	181	120	78	360	18
12	23.2	25.2	104	2.31	2.14	14.0	23.2	25.2	104	46	50	210	28

columns are the scaled peak cable currents for respectively injection point 3 (case) and over all injection points, and are again from the last column of Table 1.1. Columns 5, 6 and 7 are scaled peak cable currents for Marx injected current (see last column of Table 1.2) and are for, respectively, injection points 1, 3 and over all. Note that columns 2 through 7 all have positive values.

There exists a need to take these test results, which are from a shortened test article, and extrapolate them to what one would expect for the full sized SRB which is the flight configuration. This issue was addressed in an earlier report [1, Chapter 3 and Appendix C], with the test-to-flight conversion factors coming from a consideration of the number of apertures per unit length of the SRB systems tunnel and the average surface current densities on the systems tunnel. The first step was to separate the Marx cable responses into inductive and resistive parts and scale the inductive part by peak DI/DT and scale the resistive part by peak current value. Second, these scaled resistive and inductive Marx cable responses are added together, and also the scaled inductive Marx cable responses are added to the scaled High Current Bank cable responses, and the maximum of the two taken as worse case peak responses. Third, the proper conversion factors are then multiplied through these worse case peak responses to obtain the final flight configuration peak responses.

For these test results the scaled inductive Marx cable responses are negligibly small due to much lower high frequency coupling than before, because of the modified bond strap system. Thus, no scaling due to peak DI/DT need be performed and the peak value becomes just the maximum of either the scaled High Current Bank or scaled Marx cable peak response. So column 8 of Table 1.5 is the maximum of columns 2 and 5, column 9 is the maximum of columns 3 and 6, and column 10 is the maximum of columns 4 and 7. The test-to-flight conversion

factors for cables 6, 7 and 8 (short-circuit current) is 1.0, and is 2.0 for cables 10, 11 and 12. It is by multiplying column 8 by these factors that one gets column 11, and columns 9 and 10 produce respectively columns 12 and 13. Column 14 holds the old values [1, pages 3-7], which are for injection point 3 and should therefore be compared to the new values of column 12. Columns 2, 5, 8 and 11 are for injection point 1 and are included here for comparison with Chapter 2 results.

Table 1.6 shows the peak responses for the open circuit cable voltages in the same manner as Table 1.5 did for the short circuit cable currents. For open circuit cable voltages, the test-to-flight conversion factor for cables 6, 7 and 8 is 3.1 and is 2.0 for cables 10, 11 and 12.

Table 1.6

Tabulation of Peak Scaled Open Circuit Cable Voltages, Ending With Flight Configuration Cable Currents. Top Row is Column Number for Easy Reference

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cable #	HCB 1 Volts	HCB 3 Volts	HCB All Volts	Marx 1 Volts	Marx 3 Volts	Marx All Volts	Peak 1 Volts	Peak 3 Volts	Peak All Volts	Flight 1 Volts	Flight 3 Volts	Flight All Volts	Flight Old (3) Volts
6	19.5	N/A	19.5	N/A	N/A	9.54	19.5	N/A	19.5	61	N/A	61	316
7	3.42	N/A	3.42	0.841	3.40	4.47	3.42	3.40	4.47	11	11	14	87
8	7.88	17.1	17.1	0.720	1.85	3.05	7.88	17.1	17.1	24	53	53	276
10	3.80	6.20	6.20	1.40	1.80	7.90	3.80	6.20	7.90	7.6	12	16	22
11	4.36	N/A	4.36	3.70	3.61	8.30	4.36	3.61	8.30	8.7	7.2	17	64
12	3.71	N/A	3.71	N/A	N/A	8.80	3.71	N/A	8.8	7.4	N/A	18	20

CHAPTER 2

DEMONSTRATION OF LINEAR EXTRAPOLATION OF SWEPT CONTINUOUS WAVE TESTING TO NASA LIGHTNING SPECIFICATION

2.1 Introduction

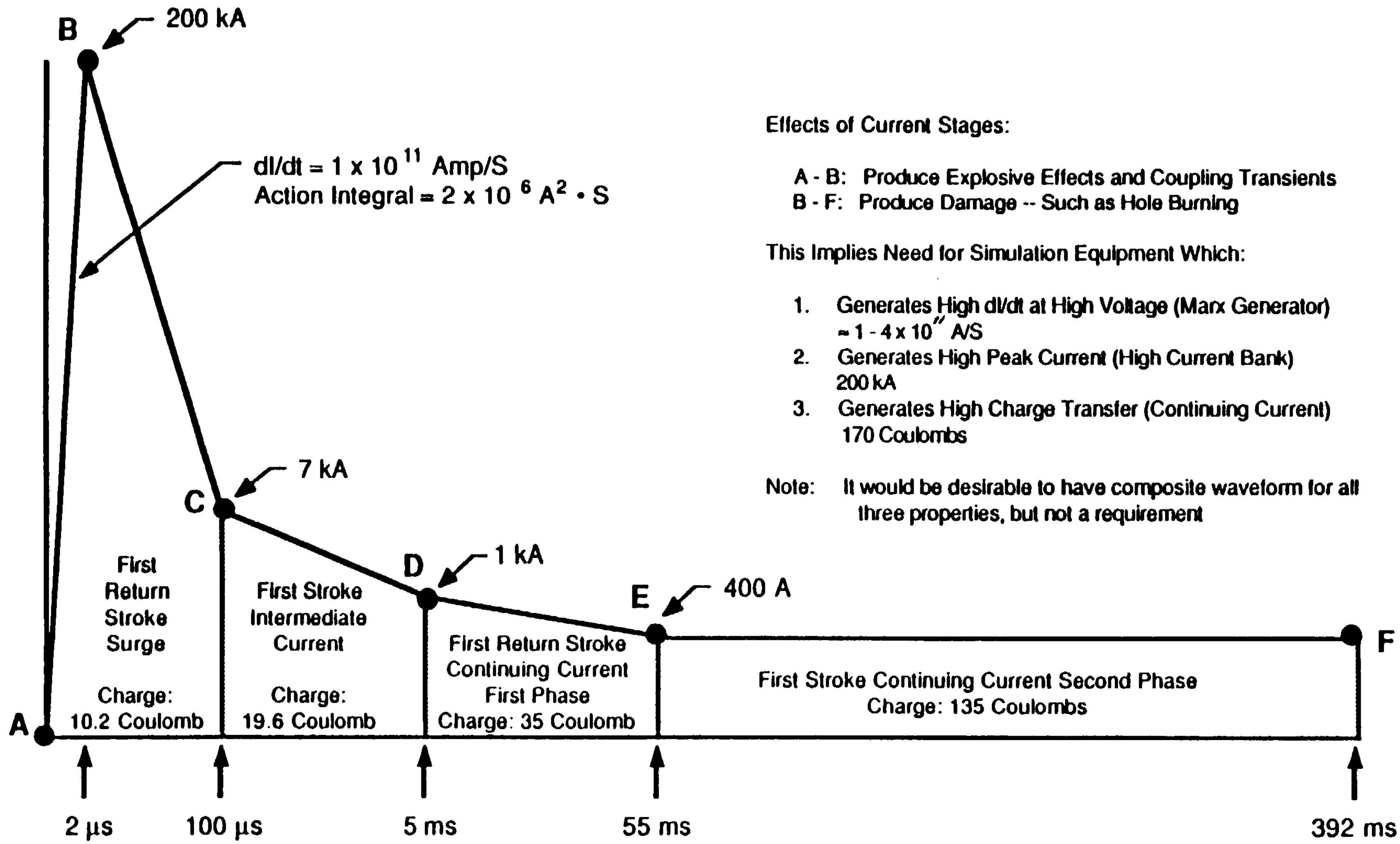
Figures 1.1 and 1.3 show typical test waveforms from respectively the Marx and High Current banks at the Wendover facility. Figure 2.1 shows the 200 Kilo-Ampere NASA lightning specification. The Marx generator is designed to provide the high initial time derivative of the lightning current (DI/DT) from the NASA specification [3], and the High Current bank provides the high action integral. However, there remains an important question concerning the spectral content of the Marx and High Current bank test waveforms which are both bipolar (ringing), versus that of the unipolar NASA specification waveform. A ringing pulse tends to have the majority of its energy concentrated near its dominant frequency, whereas a unipolar pulse usually has its energy spread across the spectrum, monotonically decreasing in value from low frequency to high frequency.

This chapter addresses this question by demonstrating how one can take the transfer function obtained from swept continuous wave (swept CW) testing and by means of simple Fourier analysis generate the time domain signal on a cable that the NASA specification itself would create.

2.2 Demonstration of Capability

The performance of swept CW measurements is in theory simple, requiring an input current that is set at a particular magnitude and frequency, and then the corresponding magnitude and phase shift of the response (short-circuit cable current, etc.) is measured. The ratio of these two quantities is usually taken and the magnitude plotted as the frequency of the input current is swept through a certain range. This then gives a transfer function for the cable response given the input stimulus.

Figure 2.2 shows the swept CW measurement transfer function for the short circuit current of USBI cable #6 given the input current injected at injection point #1 (systems tunnel cover). A previous report [1, pages 2-9 through 2-12] described how these swept CW measurements are made, indicating the placement of the cable current probe inside the measurement box. Figure 2.2 was made with the current probe on cable #6 in the forward measurement box, and Figure 2.3 was made with the current probe just hanging free with no cable going through it, giving a noise floor measurement for Figure 2.2 which consists of noise plus signal. Note that eighteen (18) decibels should be subtracted from the entire frequency range in both Figures 2.2 and 2.3.



Effects of Current Stages:

A - B: Produce Explosive Effects and Coupling Transients
B - F: Produce Damage -- Such as Hole Burning

This Implies Need for Simulation Equipment Which:

1. Generates High dI/dt at High Voltage (Marx Generator) $\approx 1 - 4 \times 10^{11}$ A/S
2. Generates High Peak Current (High Current Bank) 200 kA
3. Generates High Charge Transfer (Continuing Current) 170 Coulombs

Note: It would be desirable to have composite waveform for all three properties, but not a requirement

Figure 2.1 Ground Lightning Specification - Full Threat Parameters (JSC-07636 Revision D) (Not to Scale)

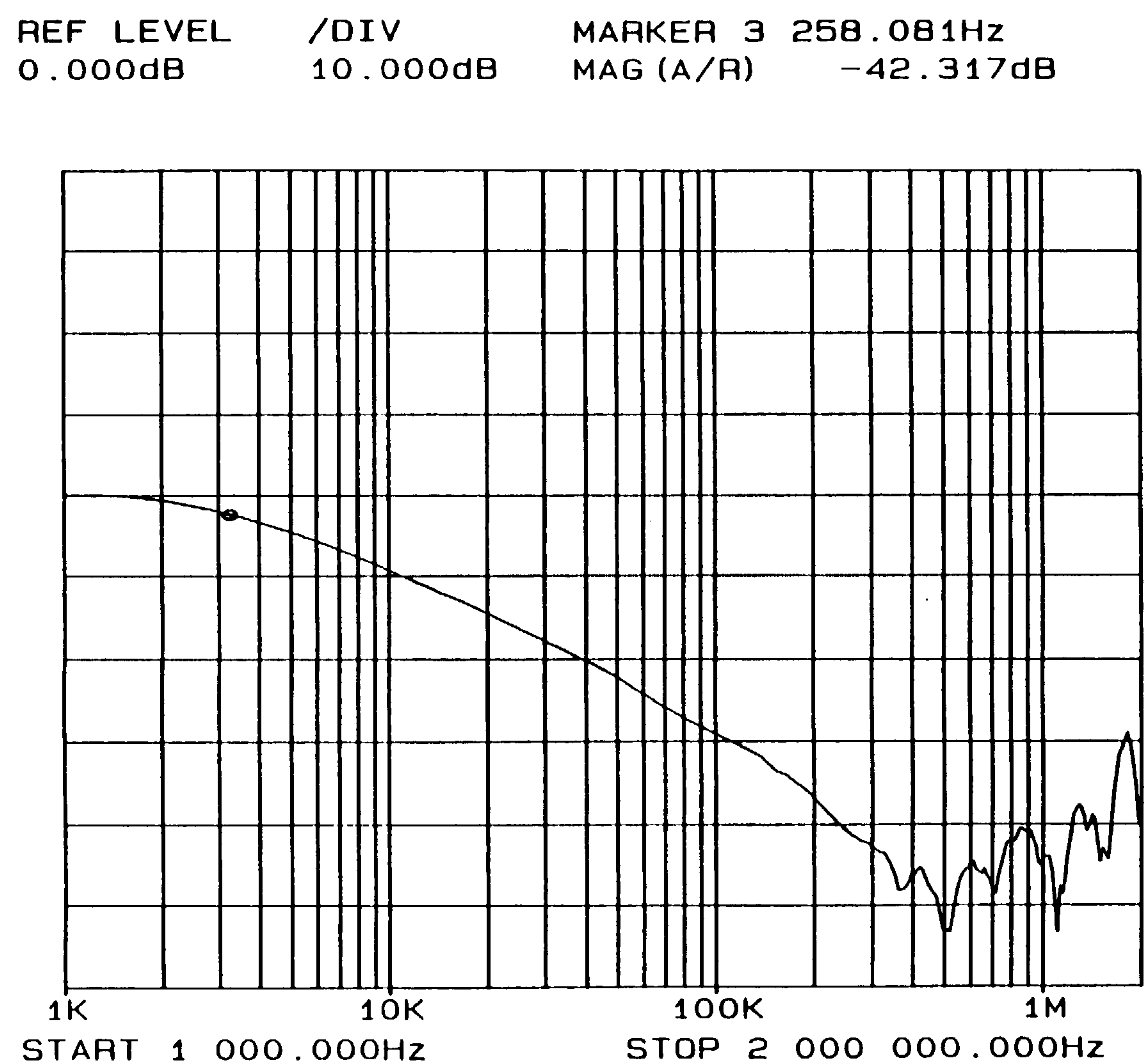


Figure 2.2 Swept CW Transfer Function for Cable 6 Short Circuit Current at Attachment Point #1 (Forward Tunnel Cover). Consists of Signal plus Noise. Needs Eighteen (18) Decibels Subtracted from it Plot CW-64

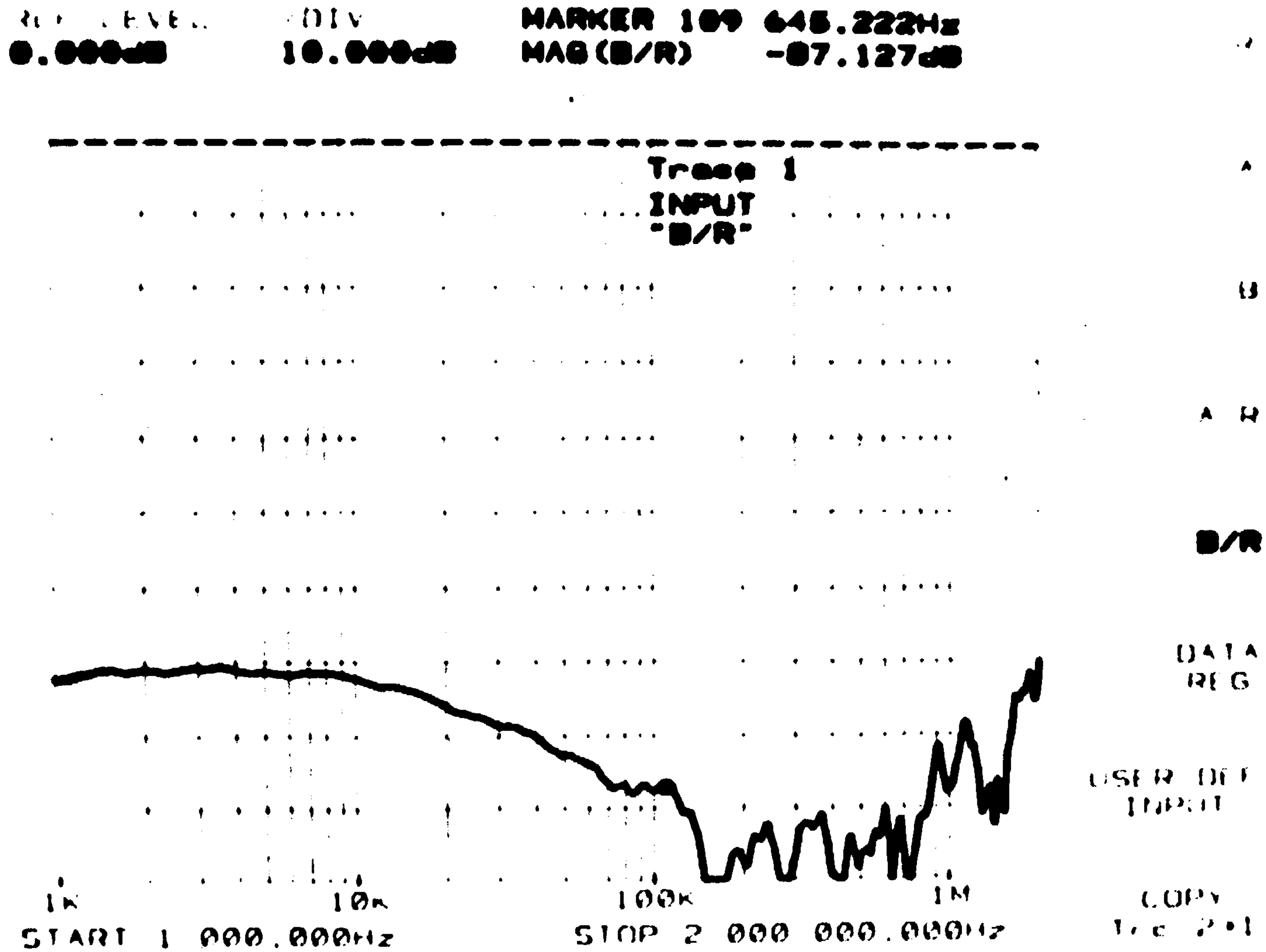


Figure 2.3 Noise Floor for Figure 2.2. Needs Eighteen (18) Decibels Subtracted from it. Plot CW-2

Figure 2.4 shows as a solid curve the noise curve of Figure 2.3 and as a long dashed curve the noise plus signal curve of Figure 2.2, both with the eighteen decibels subtracted. These curves were digitized from Figures 2.2 and 2.3 and fit with splines. The short dashed curve is the signal curve, obtained from subtracting the solid curve (noise) from the long dashed curve (noise plus signal). This subtraction was done in real units and not decibels. It can be seen that there is a very good signal-to-noise ratio up to around 200 KHz, but though there is a bad ratio above 1 MHz the signal level is so low that it can be ignored.

The next step is to recover the phase given the magnitude in the frequency domain as shown by the short dashed curve (cable 6, injection point 1 short-circuit current transfer function) in Figure 2.4. This is a standard practice in digital signal processing known as the minimum phase technique. It hinges upon a relationship between causal signals and the Hilbert transform [2], and is presented in Appendix A. One might think that there are an infinite number of different phases for a given magnitude for a transfer function. This is true, but only one of those will yield a causal time domain pulse, where "causal" means that the time domain pulse has zero value for all time prior to the beginning of the pulse. Figure 2.5a shows the cable 6 short-circuit current transfer function magnitude (same as the short-dashed curve in Figure 2.4) and its recovered phase in Figure 2.5b.

Figure 2.1 gives the NASA 200 kilo-ampere lightning specification. The main features of this waveform is that it peaks at 200 kilo-amperes in 2 microseconds and decays to 7 kilo-amperes at 100 microseconds. Figure 2.6 shows in the time and frequency domains a double gaussian fit to these two points, taking the form

$$C\left(e^{-\alpha t^2} - e^{-\beta t^2}\right)$$

in the time domain, where α=3.3539014E+08, β=2.1971835E+12, and C=2.0029907E+05.

Multiplying the output from the minimum phase technique (the transfer function) by the threat waveform (Figure 2.6b) yields Figure 2.7c which in the frequency domain is the short-circuit current induced on cable 6 given the NASA 200 kilo-ampere specification injected onto the forward systems tunnel. Figures 2.7a and 2.7b show in the time domain (on log and linear time scales respectively) what this cable 6 short-circuit current looks like, superimposed with the NASA waveform. It has a peak of 110.8 amperes at 50.15 microseconds, a considerably greater risetime than the 2.0 microseconds for the NASA specification. There is a slight negative overshoot reaching a minimum value of -3.14 amperes at 390.7 microseconds and a rise back to near zero amperes, indicating that the minimum phase technique did in fact recover a causal transfer function phase.

To better understand why the risetime of the cable current is so much slower than that of the NASA lightning waveform, Figure 2.8 was plotted. It shows the smoothed NASA specification (Figure 2.6b) as a solid curve, the cable 6 short-circuit current transfer function (Figure 2.5a) as a long-dashed curve, and their product yielding the

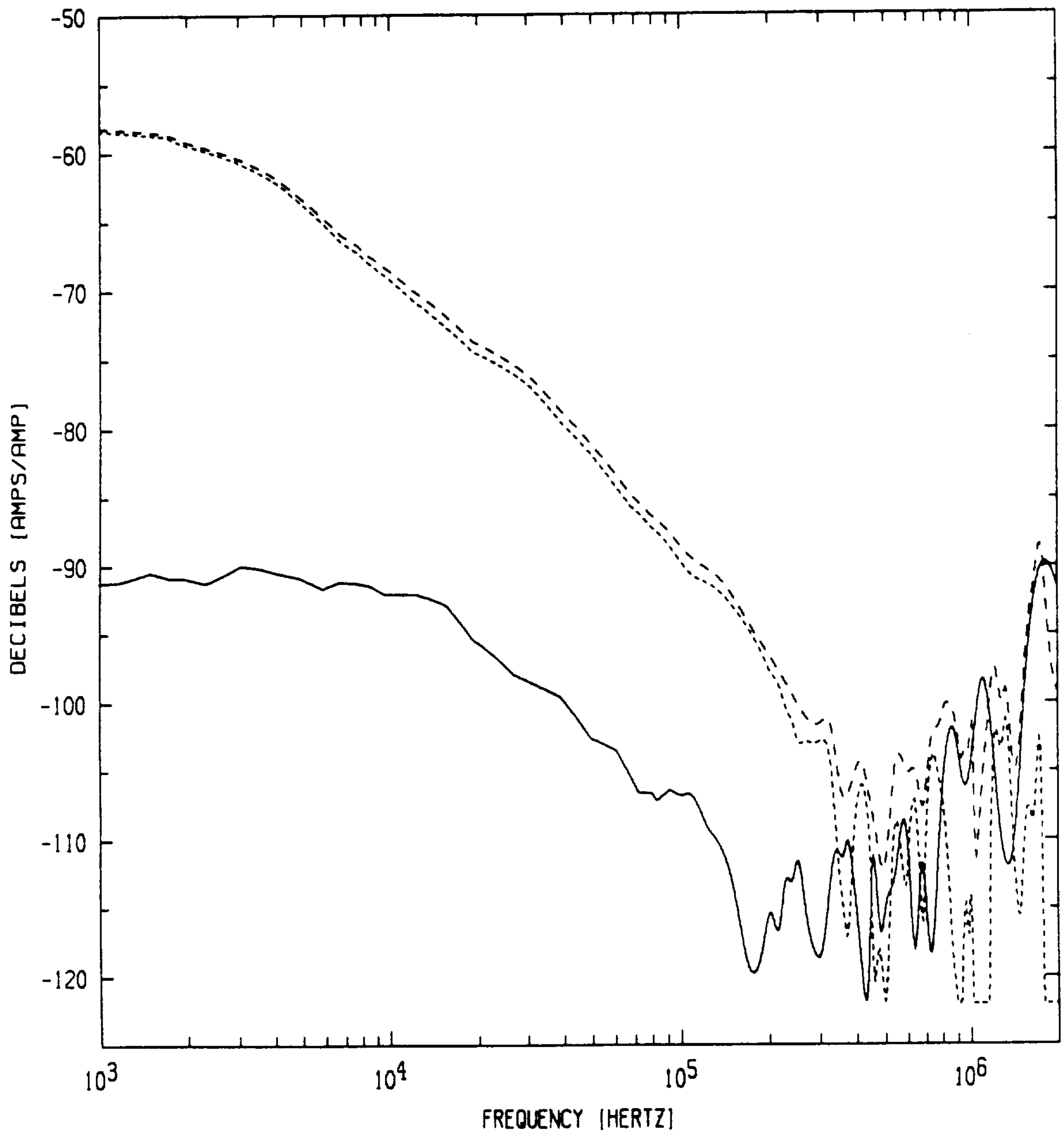
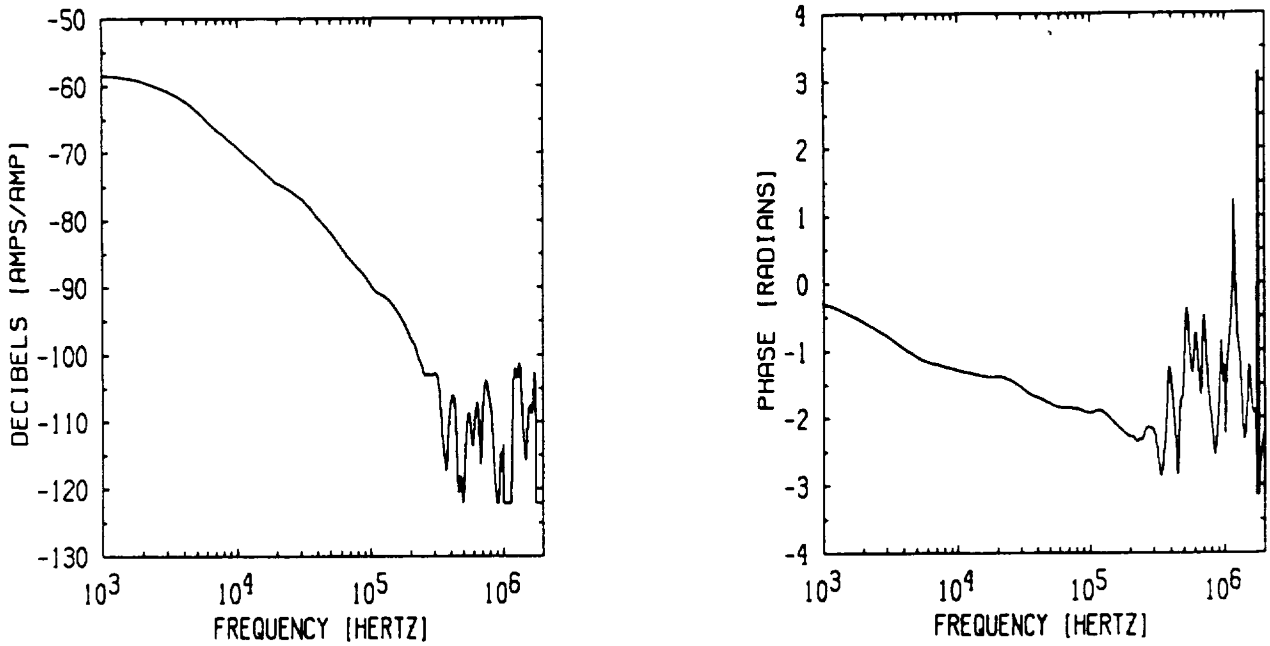
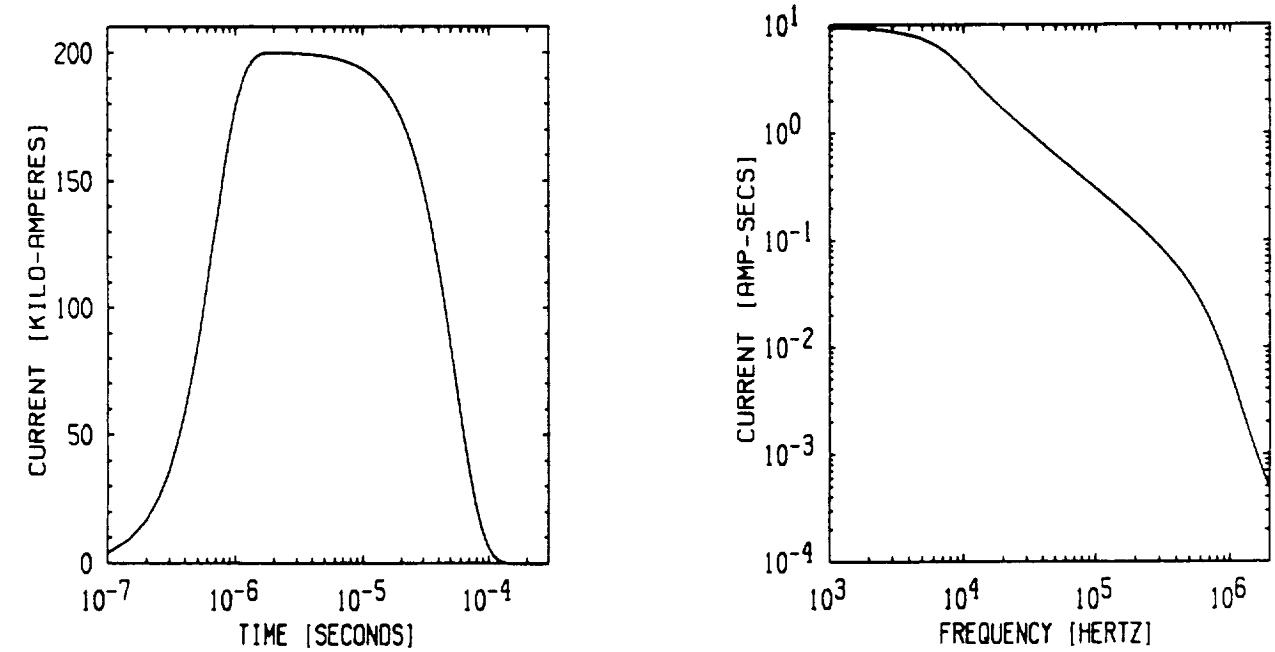


Figure 2.4 **Extraction of Cable 6 Swept CW Signal (Short Dashed Curve). Solid Curve is from Figure 2.3 (Noise) and Long Dashed Curve is from Figure 2.2 (Signal plus Noise)**



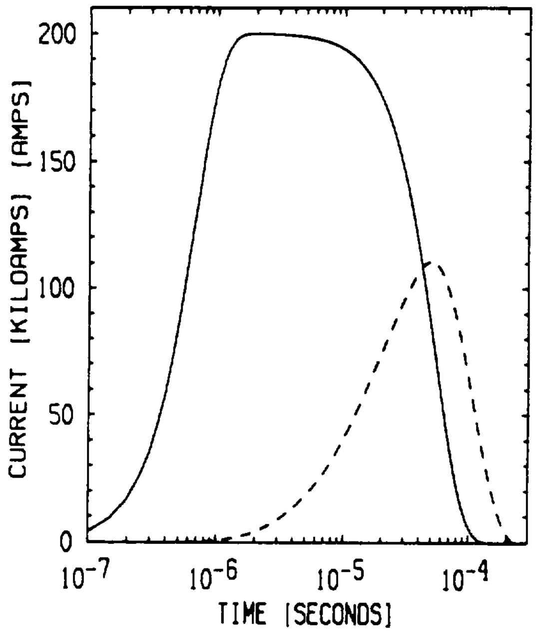
(a) (b)

Figure 2.5 **Cable 6 Swept CW Signal (Figure 2.5a, same as Short Dashed Curve of Figure 2.4) and its Recovered Phase (Figure 2.5b)**

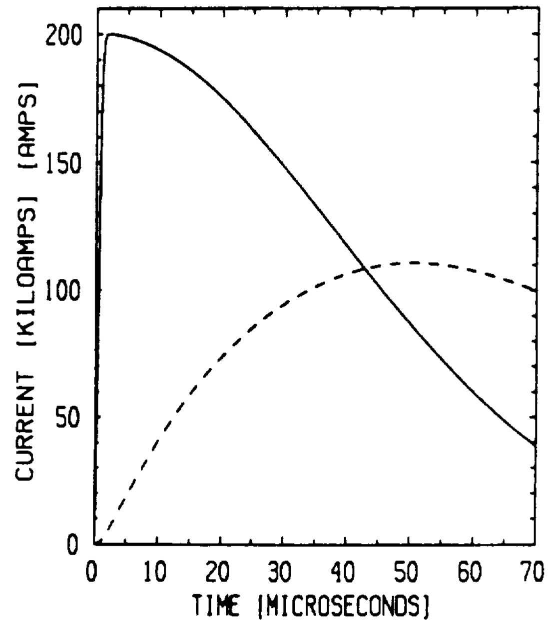


(a) (b)

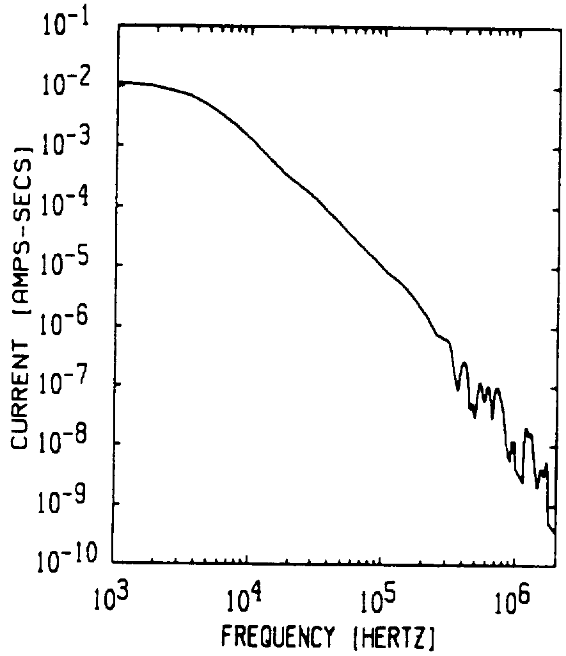
Figure 2.6 **Smoothed Double-Gaussian Version of NASA Specification (Figure 2.1) in Both Time (2.6a) and Frequency (2.6b) Domains**



(a)



(b)



(c)

Figure 2.7 Cable 6 Short Circuit Current Induced by Smoothed NASA Specification (Figure 2.6). Frequency Domain Current Shown in 2.7C, and Time Domain (Log 2.7A, Linear 2.7B) Current Superimposed With Smoothed NASA Specification

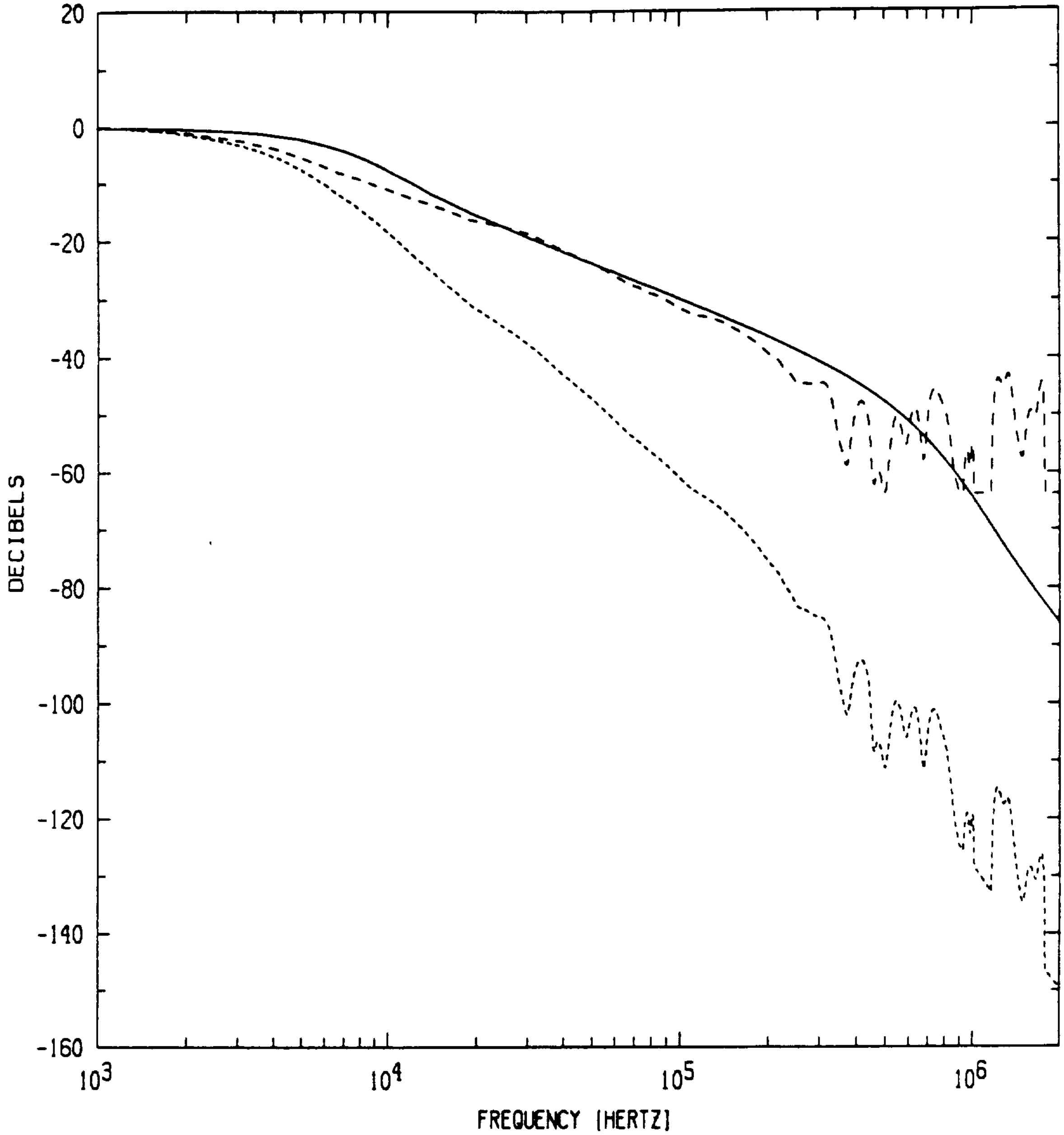


Figure 2.8 **Shifted Curves Showing Low-Pass Filter Effect of the Swept CW Transfer Function for Cable 6. Solid Curve is Smoothed NASA Specification (Figure 2.6b), Long Dashed Curve is Cable 6 Transfer Function (Figure 2.5a and 2.4), and Short Dashed Curve is Cable 6 Short Circuit Current (Figure 2.7c)**

short-dashed curve (Figure 2.7c). All three curves have been shifted so as to have value zero (0) decibels at 1 kilohertz. It is obvious that the NASA specification (solid curve) has a much greater high frequency content than that of the resulting cable 6 short-circuit current (short-dashed curve). It is because of this much lower high frequency content that the time-domain risetime for the cable 6 short-circuit current is so much slower than that of the NASA specification. In short, the transfer function (long-dashed curve) acts as a low-pass filter, clipping away the higher frequencies that contribute to a faster risetime.

Figures 2.9, 2.10 and 2.11 show the transfer function signal extraction for cables 7, 8 and 11 respectively just as Figure 2.4 did for cable 6. Figures 2.12, 2.13 and 2.14 show the time and frequency domain signals for cables 7, 8 and 11 respectively as Figure 2.7 did for cable 6. Table 2.1 gives the risetime and peak short circuit cable current values for the four cables analyzed here, as well as the scaled test values (from column 8 of Table 1.5). Both values are for peak short circuit cable current values given 200 KA current injection at point 1 (forward systems tunnel), and their differences are due to the different techniques employed.

Table 2.1

Rise Time and Peak Short Circuit Cable Values for Linear Swept CW Extrapolation, and Peak Short Circuit Cable Values for Linear High-Level Testing Extrapolation. 200 KA Current, Injection Point 1 (Forward Systems Tunnel)

Cable #	Swept CW Rise Time (microseconds)	Swept CW Peak Current (amperes)	High Level Testing Scaled Peak Current (amperes)
6	50.15	110.8	109
7	47.60	167.1	37.1
8	44.95	193.0	88.4
11	46.40	16.38	58.8

2.3 Final Remarks

The results of this chapter are contingent upon the assumption of linearity, i.e. doubling the injected current doubles the response. For low injection current levels this is a very reasonable assumption, but is not necessarily true for a pulse with a 200 kilo-ampere peak which may create electric fields high enough to break down air and thus induce corona and arcing, as well as physically burning and blasting various portions of the test article. However, the general trend for non-linear effects is to decrease cable coupling, resulting in smaller cable short-circuit currents and open-circuit voltages from an actual high-level test than one would obtain from scaling linearly from a low-level

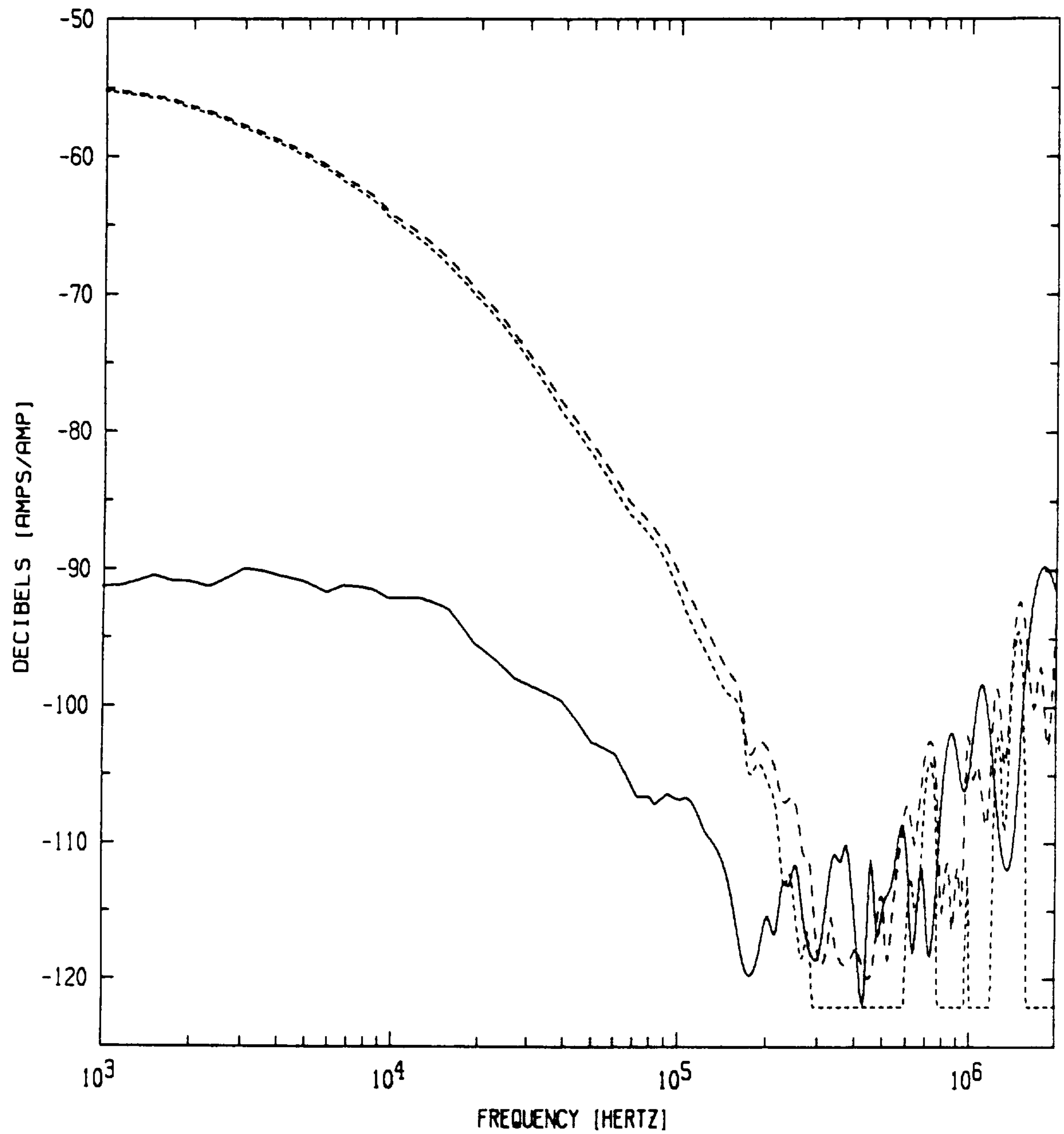


Figure 2.9 **Extraction of Cable 7 Swept CW Signal (Short Dashed Curve). Solid Curve is from Figure 2.3 (Noise) and Long Dashed Curve is from Plot CW-66 (Signal plus Noise)**

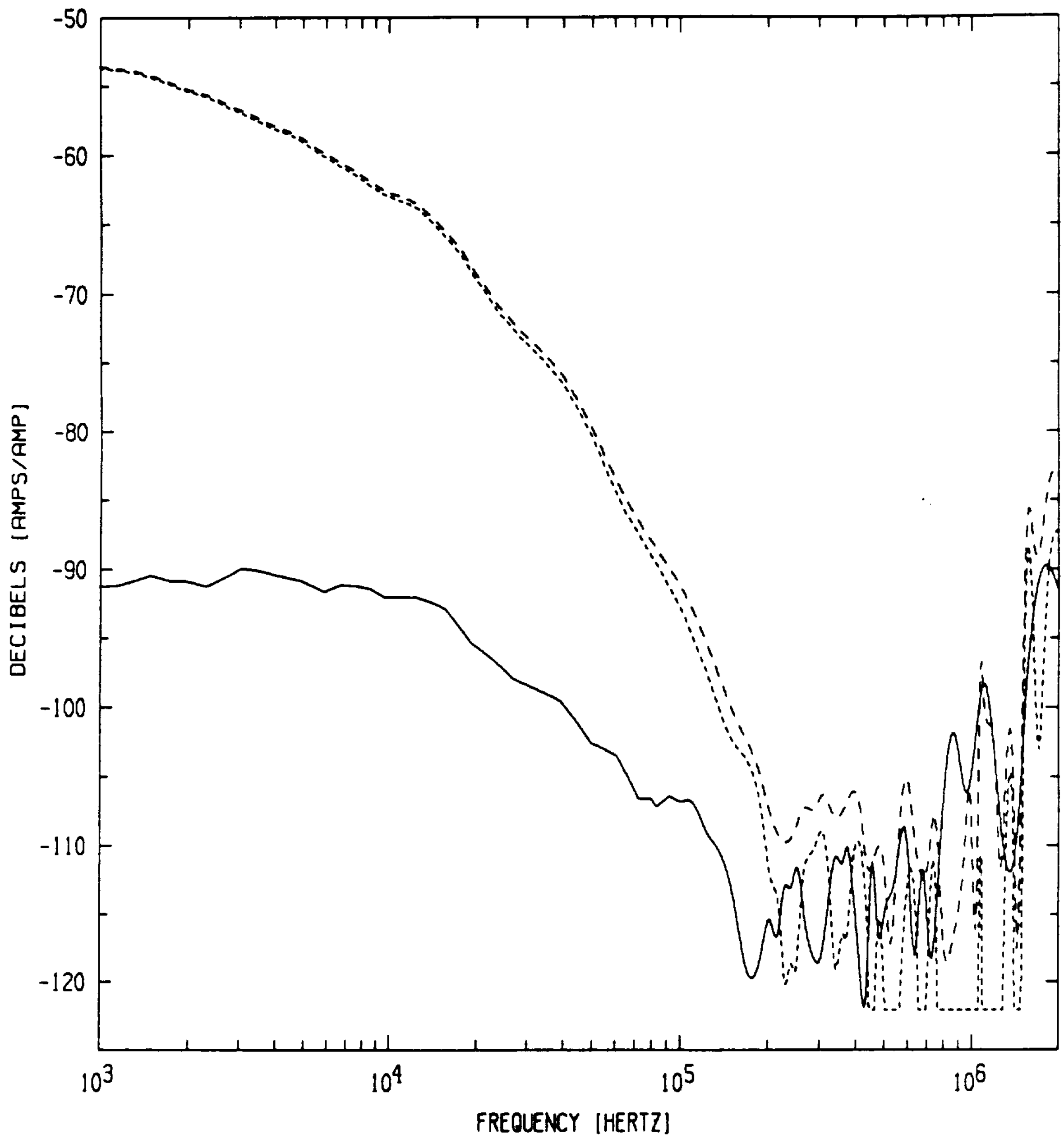


Figure 2.10 **Extraction of Cable 8 Swept CW Signal (Short Dashed Curve). Solid Curve is from Figure 2.3 (Noise) and Long Dashed Curve is from Plot CW-70 (Signal plus Noise)**

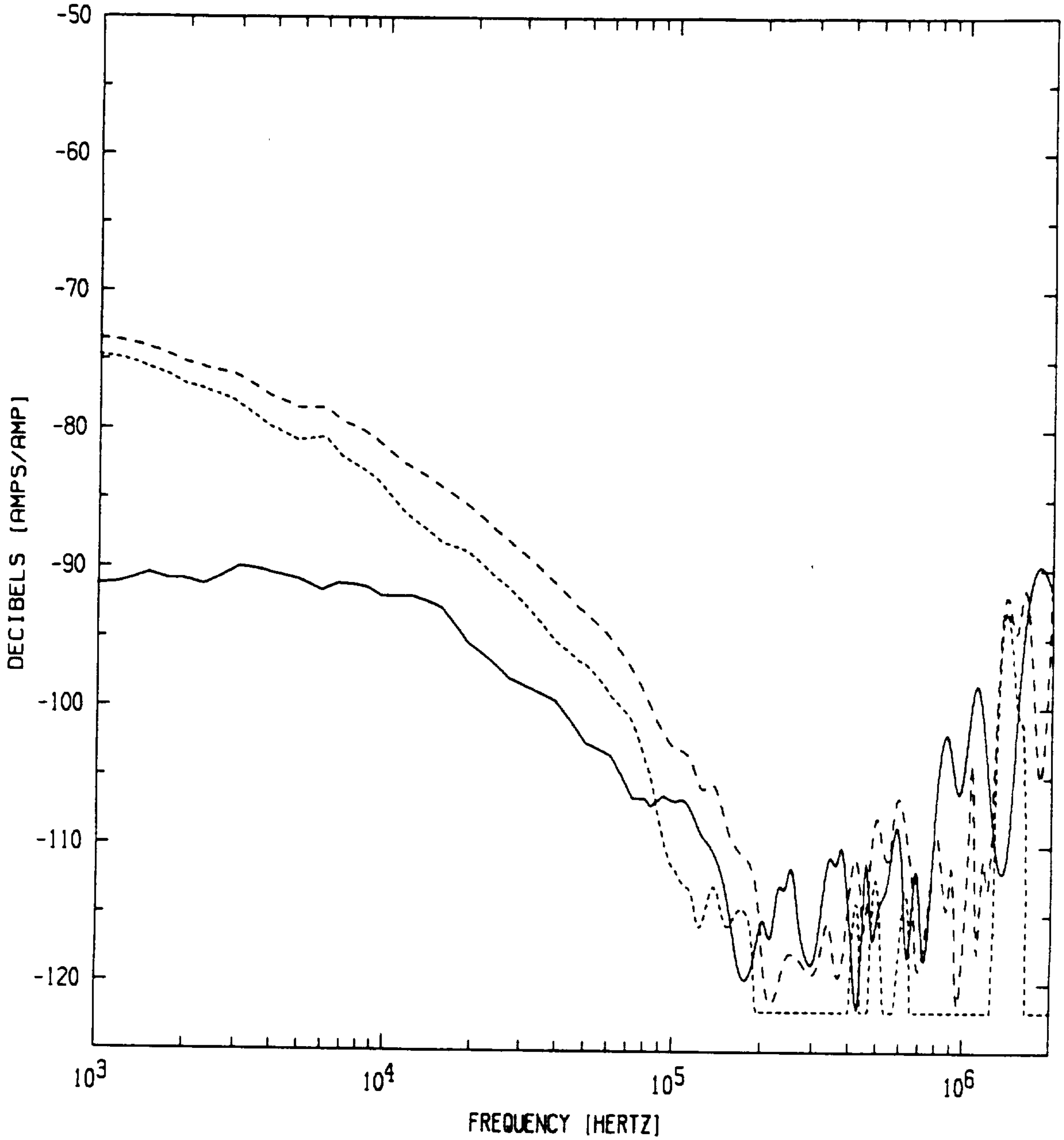
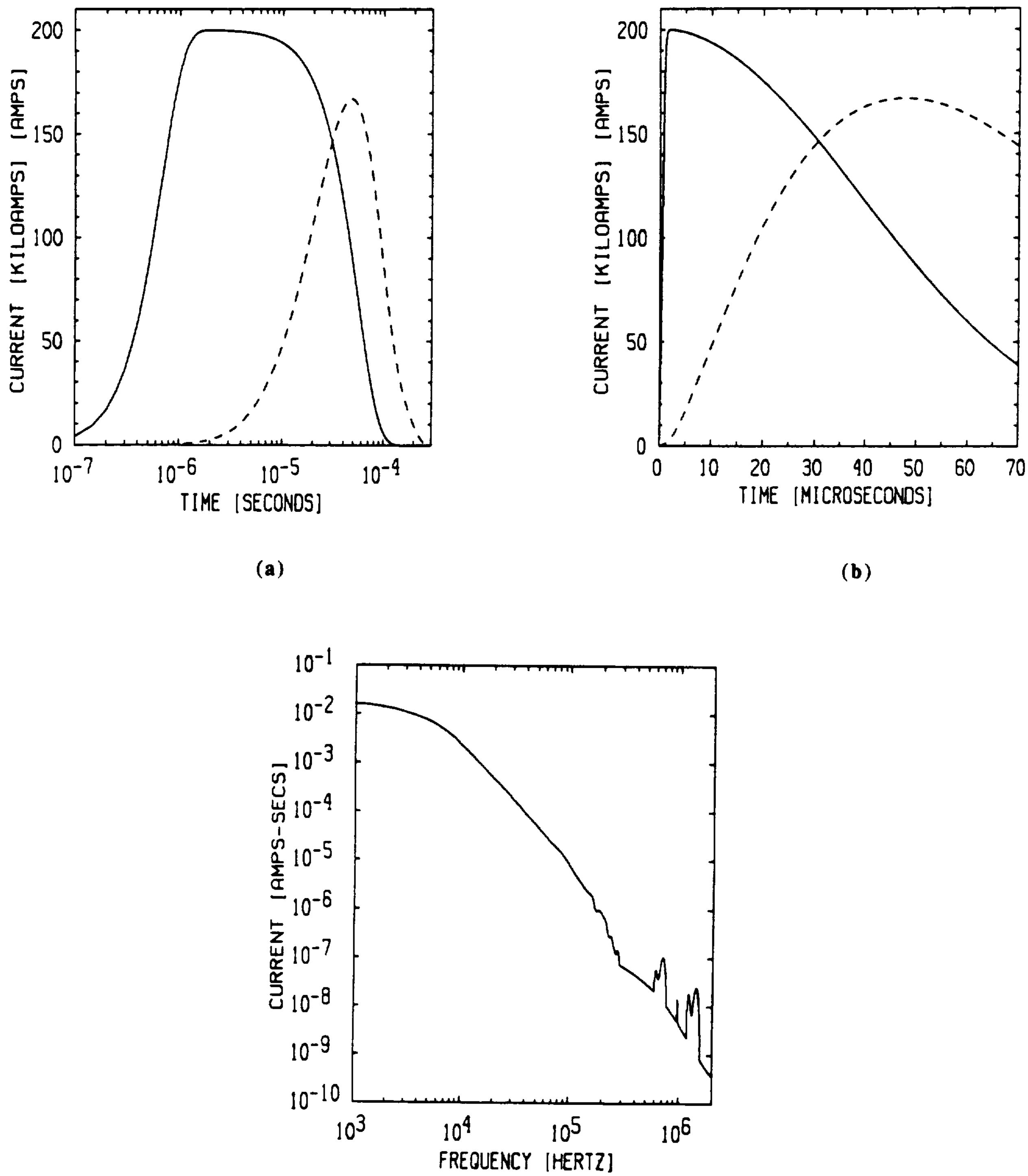
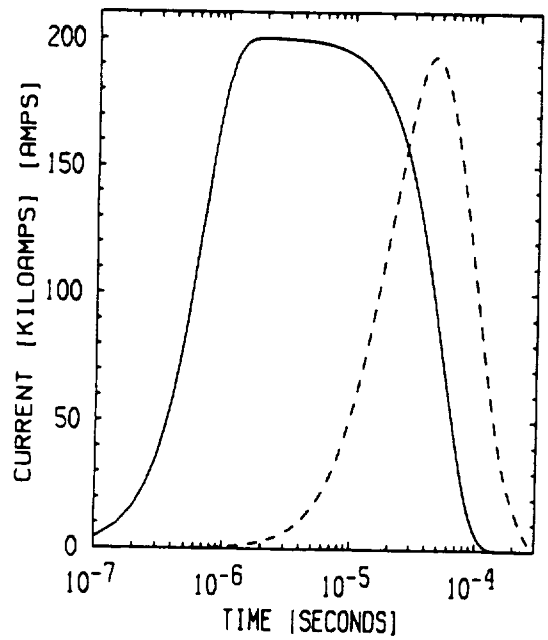


Figure 2.11 **Extraction of Cable 11 Swept CW Signal (Short Dashed Curve). Solid Curve is from Figure 2.3 (Noise) and Long Dashed Curve is from Plot CW-67 (Signal plus Noise)**

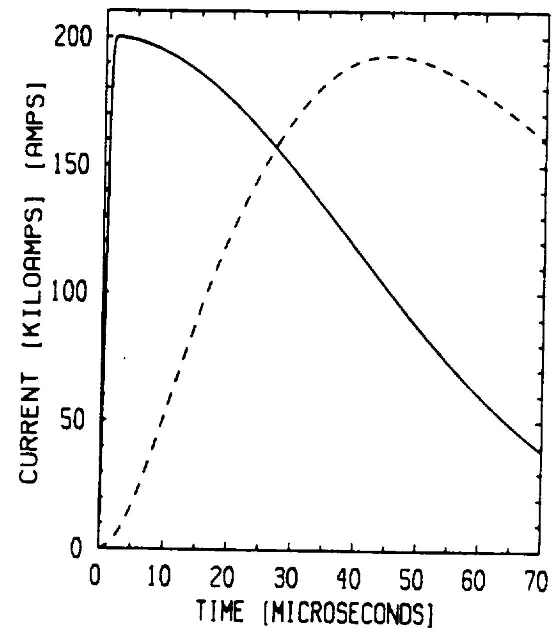


(a) (b) (c)

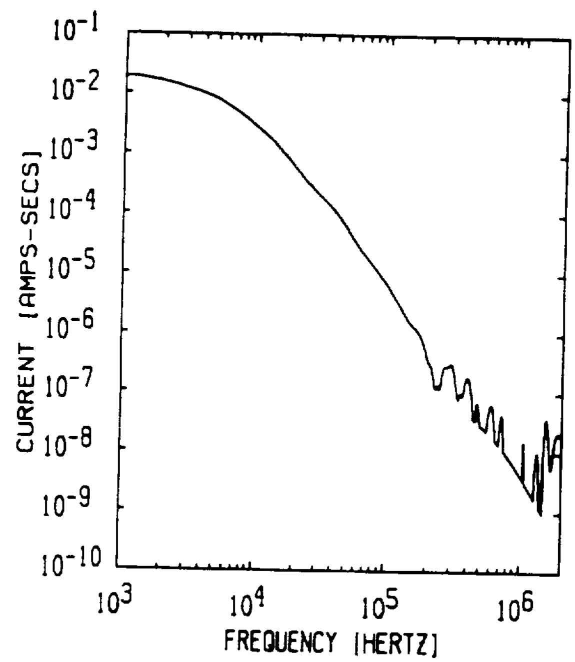
Figure 2.12 Cable 7 Short Circuit Current Induced by Smoothed NASA Specification (Figure 2.6). Frequency Domain Current Shown in 2.12c, and Time Domain (Log 2.12A, Linear 2.12B) Current Superimposed With Smoothed NASA Specification



(a)



(b)



(c)

Figure 2.13 Cable 8 Short Circuit Current Induced by Smoothed NASA Specification (Figure 2.6). Frequency Domain Current Shown in 2.13c, and Time Domain (Log 2.13A, Linear 2.13B) Current Superimposed With Smoothed NASA Specification

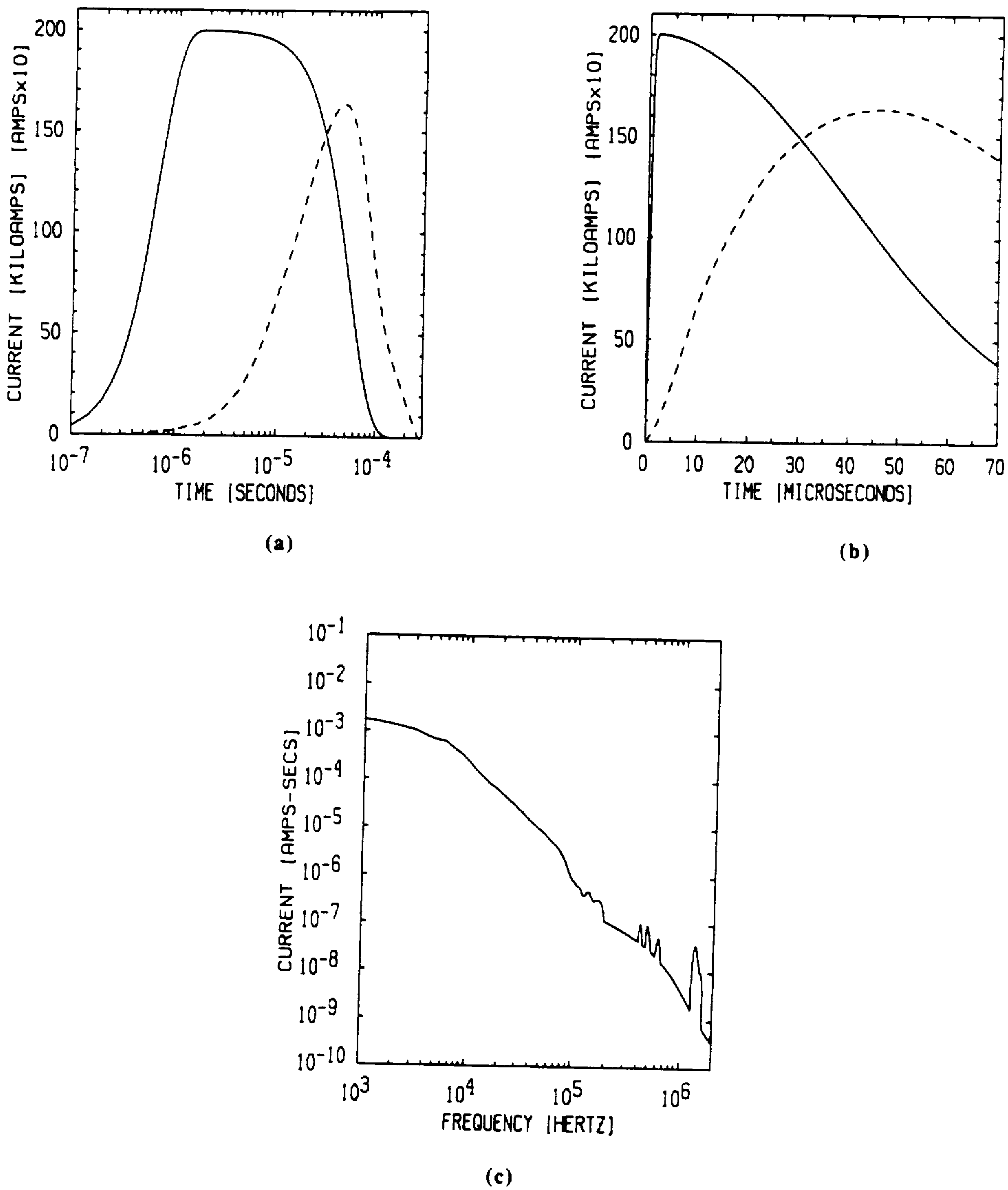


Figure 2.14 Cable 11 Short Circuit Current Induced by Smoothed NASA Specification (Figure 2.6). Frequency Domain Current Shown in 2.14c, and Time Domain (Log 2.14A, Linear 2.14B) Current Superimposed With Smoothed NASA Specification

test. Therefore, linear extrapolation should usually provide an upper bound on the cable's transient responses due to threat-level testing.

This should not however be construed as saying that threat-level testing is not useful. The actual performance of threat-level testing will probably yield a lower upper bound on the cable's transient responses (due to the nonlinearities) which could result in a lower expense for enacting shielding measures on the cables and lower weight. Also, physical effects (burning, etc.) can only be determined by threat-level testing.

One must keep in mind that the results of this chapter are for the test article at the Wendover test site, and not for the in-flight configuration. The Wendover test article is a shortened version of the actual Space Shuttle Solid Rocket Booster, and one would expect that the coupling through the systems tunnel would be different for the in-flight configuration, and that the longer cables would have different resonant frequencies.

The swept CW measurements presented in this chapter were made primarily for the purposes of gaining a better physical understanding of the test article, determining the main resonant frequencies, and checking the relative coupling levels between different cables. Therefore only the magnitude was recorded. It is always possible to use the minimum phase technique to recover the phase, as was done here, but in practice it is a relatively simple procedure to store the measurement digitally on a computer, thus saving both the phase and magnitude. Also, the confidence that one can have in using the technique of this chapter is dependent on obtaining a good signal-to-noise ratio for the swept CW measurements. For the examples given here, that ratio is in general very good and is only bad at high frequency where the coupling is so small as to be negligible.

Though not without qualifications, it would seem that the technique demonstrated in this chapter could be an invaluable tool to determining cable transient responses. Swept CW is by nature non-destructive and can be inexpensive, requiring only off-the-shelf instrumentation and a small crew to perform it, and is relatively safe since no high-voltage equipment is required.

One is not limited to just using the NASA lightning specification with this technique. Typical frequency-domain current injections by the Marx and High Current banks can be used. After performing the swept CW measurements, one could take a long break and see what cable transients should be induced by the current banks, pick the worse cases (combinations of cables and injection points), and then confirm by threat-level testing. In this manner one could reduce the amount of threat-level testing required.

Finally, because of the non-destructiveness of swept CW, this technique can be used on hardware that one would dare not use threat-level testing on, such as the actual SRB in-flight configuration as assembled and mated to the rest of the Space Shuttle.

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